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BUILDING-STONES—ELEMENTS OF STRENGTH IN THEIR CONSTITUTION AND STRUCTURE.*

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The imperfect and insufficient methods hitherto in vogue, for determination of value of stones for purposes of construction, have produced a general dissatisfaction and consequent neglect which are to some extent reasonable and within excuse. They are unsatisfactory because mostly antique, devised at a time when little was known of the internal nature of the material to which they were applied, when an exaggerated view was prevalent in regard to the homogeneity of stone, at least in each locality, and when little effort

*Abstract published in *Stone*, 1898, and elsewhere. Reference has been made in the notes to the more important statements which have appeared in the literature of the subject, during the year since the reading of this paper, concerning points discussed herein.

was or could be made toward correlation of observations and tests applied to its different properties. The classic monograph of Q. A. Gillmore,* which still remains the basis of certain methods and data accepted throughout the literature of this subject, affords abundant and unfortunate examples of imperfections and errors. A large amount of similar work has since been done throughout the country whose results, if published, would be for the most part of as limited value, from absence of exact study and descriptions of the specimens, for identification, and of other comparative tests. This scantiness of data and consequent inefficiency of result marked the exhaustion of knowledge of the characteristics of stone at the early period of its investigation—a period, however, which was distinguished for much anxious care as to proper choice and use of stone in construction. The rich sources of information on this subject, now supplied by petrographical research, suggest the need of a general review and complete revision of all these methods, for correction of our present store of data from the new standpoint, by all interested in the investigation of this important structural material.

The present neglect of known methods of trial, with the slight progress yet made toward their improvement, results too often in the haphazard selection and use of stone, rather from views of convenience, assumed experience, economy, beauty of color-scheme and adaptability to decoration, than from regard to strength and durability; in fact, often with apparent indifference whether the food for the stonecutter's chisel shall turn out, under the tests of continuous pressure and of weathering, to be "fish, flesh, fowl or good red herring." One builder contents himself with a test or two on the compressive strength of a sample of new stone; another may call for a complete chemical analysis of the sample in question, and thereby his judgment is lulled to rest; another satisfies himself with conclusions from observations on venerable buildings erected within a period of ten or twenty years past (what more can an American want!), or even with a

* Report on Building-Stones (1876), tables, pp. 32-37.

similar stone for a longer time, though often under entirely different conditions and climate, in any old country, such as Italy, Greece or Spain. The engineer is inclined to put chief or entire reliance on experimental trials of the resistance of stone to stress, applied in various ways; the chemist on determination of its ultimate composition. The physicist supplies a series of interesting tests of important properties, specific gravity, absorption-power, resistance to oxidation, etc. A geological expert is apt to rest his conclusions mainly on study of natural exposures in vicinity of the quarry. General experience, however, testifies to the mistake of neglecting that thorough preliminary examination of a building-stone, at least for important constructions, which may involve all these and other well-known processes, though they may require weeks or months of competent and exhaustive investigation. Considerations of assumed economy, particularly when a contract has been limited in time, or where stones from several quarries would be required, have usually led the constructor to dispense with these. The deplorable results have been familiar to all in masonry fractured and crumbling before its own completion, as observed during erection of the State Capitol at Albany, N. Y., the State House at Hartford, Conn., the Philadelphia City Hall, etc.

The extent and difficulty of the needed investigation result from the complexity of materials, forms and structures comprised in a stone. At a glance at the magnified picture* of its internal constitution (such as that shown in *Fig. 1*), the thought arises: "What complicate variety, what lawless disorder! Little wonder that a half dozen sciences—mineralogy, petrography, geology, physics, mechanics, engineering—must be summoned to our aid!" But the architect or engineer can be as rarely conversant with the mineralogical constitution and petrographical structure of the material he so freely handles, as the geological or chemical expert with the variety of excellent experimental tests which have

* All photo-micrographs in this paper represent a magnifying power of 40 diameters.

been designed for its exploration. It is into this borderland of apparent crystal chaos that you are invited to enter, to consider, from the point of view of modern petrography, the elementary conditions on which the strength and value of building-stone depend. Until these shall have been thoroughly worked out, understood and applied, there can be little harmony or satisfaction in methods proposed for artificial investigation and trial, in modes of treatment of this material in construction and in safe processes for its artificial preservation. Such an inquiry, too, may suggest new lines of research, yet to be devised, for the purpose of clearing up vague or conflicting conceptions of the characteristics of stone.

Theoretically, its strength, as dependent upon the tenacious coherence of its particles, might be taken to imply identical resistance to every disintegrating force; whether to one of compression and fracture under load; to the tearing asunder of grains by shearing pressure during partial support of a block at but one end or at both; to pulling apart during longitudinal tension or bending; to prying away of its minerals by frost-films in their interstices; to explosion by steam within its pores, or to violent alternations of expansion and contraction during exposure to sun, to fire or to sudden chilling of heated surfaces by cold water; to the loosening effect of acid rainfalls and of all the physical and chemical agencies concerned in the process of discoloration, softening, disintegration and exfoliation by weathering.

Practically, the compressive strength of a stone, though it may reach many thousands of pounds to the square inch, may be found to bear no relationship, yet recognized, to qualities concerned in durability. An approach to coincidence in the two properties prevails, to any material extent, only in a few of the building-stones, the granites and the finer fragmental, *e. g.*, in a fine-grained sandstone of great compressive resistance, such as the brownstone of Belleville, N. J. (*Fig. 1*), with 11,000 pounds to the square inch.

Practically, also, the resistance of a stone to atmospheric attack is largely modified by climate. So that, for instance,

if we should represent the comparative durability of a series of freestones of known compressive strength, in the climates of our own continent, by graphic curves in which the abscissæ should indicate degrees of north latitude, and the vertical ordinates, percentages in a scale of comparative durability, these curves, all starting from maximum of durability at the equator, would fall slowly to about north latitude 35°, then rapidly and far between latitudes 35° and 55°, returning sharply toward the maximum throughout the arctic area. The depth of fall of each curve below that maximum, for stones of fragmental constitution, would be to some extent inversely proportional to their degrees of compressive strength. In other words, in the uniform conditions of temperature and climate which prevail in the torrid zone, and to a degree in the arctic, freestones of little or of great compressive strength are almost equally durable, and such strength needs consideration merely in reference to loads involved in construction. Within the tract of the northern temperate zone, however, the structural weakness of any freestone usually corresponds to lack of resistance to weathering agencies, to fire and to wear by attrition. With stones of crystalline character, such as marbles, dolomites and granites, no such parallelism would usually occur between the curves of structural strength and of durability. With these, far more complex conditions call for consideration, and other methods of experimental trial must be employed. Different principles apply to the stones of each class; each must have, to great extent, its own rules and its own tests. Much of the confusion in our present literature is due to the useless attempt to combine, and thus apparently to simplify, discordant conditions and conclusions.

In considering, then, the actual elements of strength, we encounter at the outset and must accept, I think, the apparent paradox that, so far as shown by investigations yet made, the strength of a stone has little to do with that of its constituent minerals. So far as we yet know, it matters little whether these consist of brittle quartz, with its compact texture (hardness, 7), or of varieties of tough feldspar, with some tendency to rift (hardness, 6 to 7), of fibrous horn-

blende or tenacious augite (hardness, 5 to 6), or of calcite or dolomite, with easy cleavage (hardness, only 2·5 to 4).

In occasional rocks, of course, some prominent property seems to be plainly connected with that of a predominant mineral-constituent, *e. g.*, the toughness of traps and many schists with that of the contained augite or hornblende, the resistance of dolomitic limestones to the probable strength of the mineral dolomite,* etc.

No determinations are yet on record, I believe, of compressive strength, resistance to weathering, to fire, etc., of the common individual minerals which make up building-stones. In their absence, how can we safely generalize concerning the irregular aggregates of minerals which we find in every rock we use? It may be anticipated that the results of such determinations on minerals will be found to vary with relation to crystallographic axes, like other physical properties already determined by the mineralogist and physicist, viz.: cleavability, hardness, tendency to solution, temperature expansion-coefficient, etc. So here, in the very beginning, is a considerable hiatus in our knowledge; we study the aggregate, the stone, in considerable ignorance of the nature of its constituents, the minerals; these yet remain to us unknown hieroglyphics of the ancient manuscript we are trying to decipher. On the one hand, we may admit the possibility that the variations of minerals, in reference to such properties, may be so limited, that they shall be ultimately found of minor importance, compared with variations in conditions of arrangement and in mutual relationship of intermixed grains. On the other, is it but a wild fancy to conceive, in reliance on the definite laws of force, that, with the pertinent physical data once established for each constituent mineral, it may yet be possible to calculate, from the grains exhibited in a few thin sections of a crystalline stone (such as the hornblendic granite of St. Cloud, Minn., *Fig. 2*), an estimate of its crushing resistance, etc., at least as approximately correct as the results now commonly deter-

* J. H. L. Vogt, "Der Marmor in Bezug auf seine Geologie, Structur und seine mechanischen Eigenschaften."—*Zeits. f. prakt. Geol.* (1898), 16.

mined for a whole quarry or group of quarries by experiments on a few cubes cut from the same block!

Objection has been often advanced to further determinations of this property, on the grounds both of the imperfections of the method and the widely discordant variations of the results thereby obtained, and also of its uselessness, since the estimated figures for crushing strength enormously exceed the actual stresses endured by stone in masonry.

As to its imperfections, these have been clearly due, in part, to vague identification of the varieties of stone under examination. For example, in Gillmore's tables, we find the term "blue granite, Staten Island, N. Y.," applied to the diabase of that locality; "Harlem stone, Morrisania, N. Y.," to indicate some kind of gneiss; the terms "dark," "light," "gray," "rose," etc., as sufficiently descriptive, in connection with the noted specific gravity, for identification of the tested varieties of stone, etc. In fact, the hasty presumption of the local homogeneity of stone has since led to common use of regional terms, such as "Maine granite," "Vermont marble," "Indiana limestone," etc., in connection with definite physical data obtained from a few specimens of limited occurrence.

Again, we find extreme variations in figures for compressive strength attributed to supposedly definite varieties: such as, "light granite, East Bluehill, Me., 12,125 to 16,250," "syenite, Cape Ann, Mass., 12,861 to 19,280," "gray granite, Peterhead, Scotland, 8,290 to 18,636," "marble, Pittsford, Vt., 11,250 to 18,750," "bluish marble, Lee, Mass., 7,705 to 17,954," "brownstone, Portland, Conn., 5,806 to 10,928," etc.

In fact, a single statement by Gillmore, "each specimen of all the kinds was carefully prepared by an expert stonecutter, and the bedside marked"—throws doubt on the accuracy of all his experimental figures, on account of the well-known weakening effect produced on stone surfaces either cut or "stunned" by blows, and the consequent inferiority of hewn to sawn cubes.* However, there is no

*T. H. Johnson obtained for the crushing strength of oolite-limestones of Indiana, when tool-dressed, 7,857 pounds; when sawn, 12,675 pounds.—Rep. State Geol. Ind., 1881, p. 45.

present need nor probability of the repetition of such errors, and we may confidently expect that the variation in figures will be minimized, in the more thorough investigations of the future, by careful and exact selection and identification of varieties of stone for trial, by improvement in the apparatus and methods of test and by uniformity in the mode of their application. The need of accurate estimation of this property in stone has been shown by repeated instances of its fracture under load in masonry, which are likely to increase with the modern tendency to erection of lofty buildings.

Again, it will become better understood that resistance to crushing and resistance to all other forms of disruption of grains in stone are equally functions of their intensity of coherence. We may therefore also hope for future researches which shall reveal the approximate relationship of all these factors, and shall supply us, for each kind of stone, with certain coefficients, as yet unknown, of resistance to disintegration by shearing, by freezing, by abrasion, etc., which may be applied to its accurately determined figure for crushing strength.

But there seems to be an additional reason not only for the continuance of this method of investigation, but for its most thorough prosecution in the future, subject to an important and hitherto neglected modification. It has been shown by Professor Hoskins* that, under a predominant pressure in one direction, a rock which is rapidly deformed may pass beyond its elastic limit and become ruptured; but when under less rapid deformation, it may simply tend to flow. Under great stresses in artificial constructions, similar conditions might be presupposed, although entirely ignored by architect and engineer. In fact, abundant evidences of permanent flexure and deformation have been observed in apparently unimportant constructions (elsewhere referred to), such as the sagging of stone beams and slabs after long suspension with partial support, and the flexure of hewn blocks

* L. M. Hoskins, "On Flow and Fracture of Rocks as Related to Structure," U. S. Geol. Survey, Sixteenth Ann. Rep. (1894–95), 847.

Fig. 1.—Sandstone.—Belleville, N. J.

Fig. 2.—Hornblendic Granite.—St. Cloud, Minn.

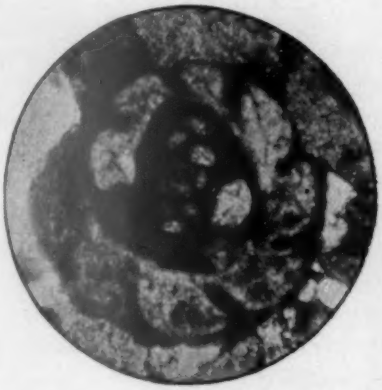

Fig. 3.—Foraminiferal Limestone. Hinesville, Ind.

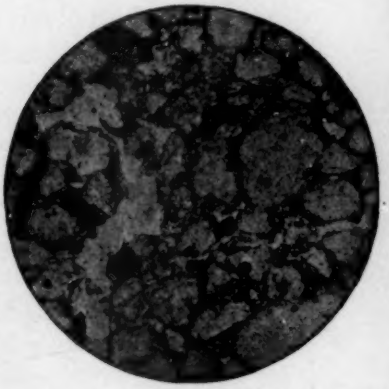

Fig 4.—Quartz-Sandrock.—New Lisbon, Wis.

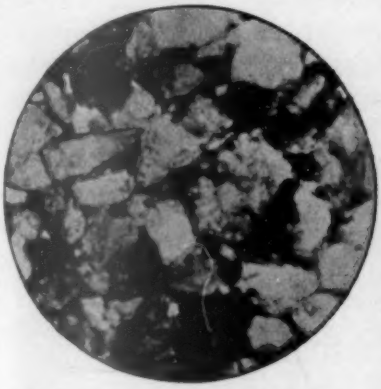

Fig. 5.—Sandstone.—Dorchester, N. B.

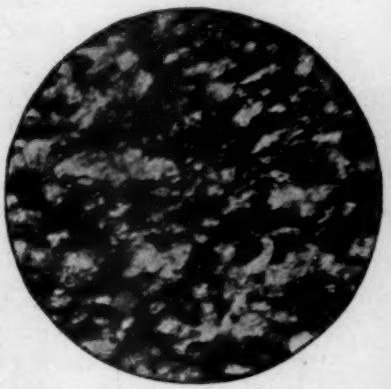

Fig. 6.—Sandstone (Bluestone).—Meshoppen, Pa.

Plate A.

of marble in quarry-yards and of stone wainscot and mantels in ancient buildings. As Van Hise observes, "This latter case shows how important the element of time is in the deformation of rocks, and that, given a sufficient time, a stress much below the ultimate strength may surpass the elastic limit and result in flowage."*

It is still to be determined whether, under pressures actually existing in the walls of lofty and massive edifices, a tendency to plasticity, yielding and flowage, rather than fracture, may not have often become developed in a hewn block of building-stone, even partially enclosed within masonry on five out of its six sides, given sufficient time. No measurements seem to have been taken on the lower blocks in lofty monuments, especially when ancient, to distinguish traces of deformation, though it may be safely presumed that such results of plasticity must have sometimes occurred.

Evidently, then, the usual method of determination of crushing resistance in stone cubes, as laid down by Gillmore, and ever since faithfully followed, has been vitiated by a serious source of error, the neglect of the element of time. On this Gillmore had only this to say, "The power applied neither fast nor slow, but steadily."†

But the experimental conditions of pressure rapidly applied beyond the elastic limit within a brief period, usually of a few minutes, differ widely from those borne by hewn stone in construction, the gradual, slow and indefinitely continued application of load. A method of experimentation is called for, founded on the gradual and slow increment of pressure during a long period, up to days, weeks or months. Gillmore's work can then be but the basis and beginning of a long called for revision of our present methods. In this conclusion I have been confirmed by the results of experiments carried on in 1886, upon a homogeneous dolomite from Western Massachusetts, and which may hereafter be published.

* C. R. Van Hise, "Principles of North American Pre-Cambrian Geology," *idem*, 594.

† Report, p. 6.

It is certainly beyond question that the blocks of hewn stone, as received by the builder, are always seamed and weakened by very minute cracks, partly superficial and partly internal, of unknown number and dimensions, often referred to as "flaws" or "checks." These are in part natural, originating in the tensions and stresses to which the rock-strata have been subjected. Others are artificial, in large part unnecessary and avoidable, having been produced during rude processes of quarrying; by the use of heavy blasting, in place of light charges properly distributed, or in a lewis-hole; by the continued application of heavy hammers, instead of channeling machines, for loosening blocks of rock;* by the rough handling and dumping of loosened masses, and even their hurling down mountain sides to facilitate transportation—the abuse to which Carrara marble is subjected; by the exposure of freshly quarried blocks to freezing temperature, with consequent flaking, fracture and development of internal rifts; and by rough hewing and dressing, the surfaces being "stunned" by heavy implements during ax- and bush-hammering.† It is this peculiar class of defects in stone which calls for special trial in compression tests, and it is readily conceivable that a cube of stone, capable of resistance to enormous pressure, many thousands of pounds, rapidly applied, might be fractured or even crushed, through gradual opening of its clefts, under a continuous load of a few hundred pounds.‡

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* T. C. Hopkins, "The Building Materials of Pennsylvania; I, Brownstones" (1896), 24–25.

† G. P. Merrill, "Stones for Building and Decoration" (1891), 397.

‡ The following conclusions, in a recent discussion of the testing of marbles, are equally applicable to other stones:

"We would expressly point out that the resistance of marble to crushing has nothing to do with the hardness of the stone. It is also not directly proportional to texture and to durability in the open air; for example, even a tolerably loosely grained dolomite-marble possesses a very considerable compressive resistance. This cannot, therefore, depend directly upon compactness of texture; the tests with cubes, of 5 to 8 centimeters on a side, are not generally of such decided value as at first thought. With excessively great overloading, marble is not usually crushed through destruction of its grain, but this results in consequence of sundry fissures and clefts, often indistinguishable by the eye; and this is not recognized by tests on cubes."—Vogt, *loc. cit.*, 44.

However, with this exception, it is not the purpose of this paper to discuss the methods of trial or test of the strength of stone, but rather the foundations on which such methods ought to rest, *i. e.*, the question, What are the chief elements of its strength? These are characteristics of fragmental or of crystalline granulation and may be comprised in four classes, represented by the terms, *interlockment*, *coherence*, *tension* or *strain*, and *rigidity*.

I. INTERLOCKMENT.

Three stages may be distinguished in the initial arrangement and progressive consolidation of mineral grains within a building-stone.

(1) *Irregular Aggregation*, in which grains of a fragmental stone occur simply heaped together in a helter-skelter mass, like jackstraws. An extreme case is found in "beach sandrock," the barely cemented agglomerates of calcareous sands on many marine beaches of the Gulf of Mexico, Caribbean Sea, Southern Atlantic, etc., *e. g.*, the so-called "marine conglomerate" of the Old Government Quarry, near Hamilton, Bermuda; also, in beds of earlier age, certain varieties, cellular and partially cemented, of oolitic and foraminiferal limestones of our Western States, such as that of Hinesville, Ind. (*Fig. 3*). In these we find fossils, grains or pebbles so irregularly disposed that each lies in mere contact with its neighbor, touching at but few points, with numerous unfilled, intervening cavities, and largely unsupported; there is generally little evidence of sorting or rearrangement by wind, water, superincumbent pressure, or motion of the mass. Other examples are offered in the ferruginous sandrock of our Atlantic Coast, sometimes used for building in Ocean and Monmouth Counties, N. J.; in some brownstones of the Trias deposits of New Jersey and Connecticut; in the friable sandrocks of the Northwest, with their rounded, poorly cemented grains, *e. g.*, that of New Lisbon, Wisconsin (*Fig. 4*), and, among crystalline stones, in some porous dolomites of Minnesota and volcanic tufas of the Western States.

In consequence of this irregular disposal of grains, stones

of this class are likely to enclose a vast abundance of small and large cavities, resulting in porous cellular texture, inferiority of compactness and weight, low compressive resistance, and enormous absorption-coefficient; all these conditions tend toward weak qualities in a building-stone. In a porous marble, limestone or cellular sandstone with calcareous cement, the cavities may afford, in a moist climate, a *nidus* for vegetable growths and consequent deep decay of the stone during weathering. Yet the loose texture may be offset in the direction of both compressive strength and resistance to weathering, by presence of strong cement, lining the cavities in the form of calcite, quartz or crystalline variety of iron-oxide; and even a porous dolomite or volcanic tufa may possess great durability, by virtue of its very insolubility. The enclosed air-cavities also favor more general uniformity of temperature through the stone, and, in a building thereof constructed, desirable protection from external variations in the climate, though often with undesirable tendency to dampness within.

(2) *Parallel Sorting.*—In fragmental stones, this position of grains sometimes results simply from their platy form, such as the shell-fragments in "coquina limestone," of St. Augustine, Flor. It may be also derived from partial sorting and rearrangement by wind, as in the calcareous sandstone of the quarries of Bermuda, known to be entirely an aggregate of shell- and coral-fragments, heaped up by gales on that ancient reef and afterwards consolidated by percolating rainwaters. Elsewhere it may be the consequence of sorting of sand-grains during deposit under water, accompanied by gradual increase of superincumbent load, forcing the larger grains to assume the position of greatest stability, *i. e.*, horizontality, and the smaller particles to ooze and pack into the adjoining cavities, *e. g.*, in the freestone of Dorchester, New Brunswick (*Fig. 5*).

In the crystalline stones, whose grains have emerged from a stage of plasticity or fusion, a similar parallel disposal has been commonly produced by intense pressure, by flow of the viscid plastic or fused material, and by a shearing movement, the tangential resultant of force which has

accompanied subterranean shiftings of the earth's crust; this is often represented in the gneiss-structure (*Fig. 7*).

The final and most complete interlockment of grains is offered in the form of

(3) *Dovetailing* or *interpenetration*.—Here those minerals, whose grains in a fragmental stone, or whose imperfect crystals, in a crystalline variety, possess the elongated form of bars, plates or prisms, have been settled down into parallel position in the bedding-plane of the original rock, or subsequently into its schist-plane, and act as a binding-material, like the hair-fibers in mortar, the straw or dung in a sun-dried brick or adobe, or the cross-bonds in masonry. These are well exhibited in the "Wyoming bluestone" of Meshoppen, Pa. (*Fig. 6*). While these plates are thus indeed presented in the readiest position for cross-fracture by pressure from above, this is more than counteracted for themselves by the completeness of their enclosure and mutual support. Within the mass itself they must exert the most powerful resistance to tearing apart of grains by longitudinal tension, through expansion by frost-films, by fire and by absorption of moisture. The extent of their influence, as elements of strength, must be proportional to their number and heightened by the associated obliteration of cavities and consolidation. They are most clearly distinguished in a thin cross-section of the stone. However, a stone in which they abound may possess but one position of stability, that of the bedding-plane. Placed on edge, the general parallelism of its grains may become a source of weakness, through the tendency to ready cleavage so imparted. Thus, in particular, the parallelism of mica-scales, which might exert a strong binding action in horizontal position, becomes a principal cause of the well-known destruction of blocks of micaceous sandstone by weathering, when erected on edge in ashlar.

These features are still more prominently displayed in the close interlockment of crystals in crystalline stones, the marbles, dolomites, traps, granites and gneisses. In these loose aggregates may indeed occur, *e. g.*, in the dolomites, composed of polygonal grains with nearly smooth and often

slightly curved faces, feebly pressed together and easily separated; or, at the other extreme, in the calcite-marbles and many granites, grains with irregular or even zigzagged outlines, roughened faces and projecting tongues, moulded upon and forced into each other, in the most intricate and inseparable form of interlockment.* The degree and effect of this mutual interpenetration may be appreciated by a study of the dovetailed masses of quartz common in most granites (*Figs. 2* and *15*). In other stones, the minerals alternate in smooth plates and lenses—it may be, of quartz, feldspars and micas—mutually intercalated and overlapping, as in the common gneiss of Philadelphia and New York (*Fig. 7*). In many, films and strings of mica are intermixed, to bind the mass still more closely, or even fibers of tough hornblende and augite lend their tenacity to the strength of the stone.†

* "In our best American marbles the edges of the crystals are clean and firm, and are often knit together like the bones of a skull."—G. W. Perry, "The Relation of the Strength of Marble to its Structure," *Eng. and Min. Jour.*, (1891), 453.

† The views of Vogt, concerning the relations of texture and strength in the marbles of Europe may be summarized as follows: Contact-metamorphic marbles (those developed in vicinity of trap-dikes) are generally loosely granular, partly because their calcite-grains, like the grains in dolomite-marbles, are not closely compacted and interlocked, and partly because the angles and edges of the other enclosed minerals (garnet, augite, etc.) are often rounded. For this reason many quarries have been given up and only a few yield solid marble. In regional metamorphic calcite-marbles (corresponding, for example, to those of Vermont, Pennsylvania and Tennessee) the solidity is mainly caused by the intricate interlockment of the calcite-grains and increased by the presence of quartz, and also by the pegmatitic texture (like that of graphic granite), where the large calcite-grains are sprinkled with many enclosed granules of the same mineral. On the other hand, a "cataclastic" character, a brecciated condition produced by crushing during dynamic metamorphism, in which both cleavage-faces and gliding-planes show curvature, indicates fragility and uselessness of the stone; a saccharoidal constitution is also somewhat unfavorable. In regional metamorphic dolomite-marbles (corresponding to those of Southern New York and Western Massachusetts), many varieties are loosely granular and worthless, the finer being even sandy to great depth; while some whose grains are less curved in contour improve below the depth of 5 meters, and become suitable for sculpture, and even for building. In most of them, however, the grains are poorly interlocked, so that the marbles are of feeble texture and inferior quality.

We must also note that, from causes never yet clearly explained, strange exceptions occur to the prevalent rule of excess of compressive strength of a stone "on bed;" a considerably increased strength "on edge" has been observed by Gillmore and others in many samples of granite, hornblendic granite, dolomite, limestone and sandstone. The source of such anomalies might have been revealed, by study of the texture of the stone, in some mode of interlockment, perhaps in the presence and position of certain natural cross-bonds. Yet this loose distinction of position of stone-cubes under experimental pressure, "on bed" and "on edge," which was sufficient for the purposes of twenty years ago, will need hereafter to be supplanted by close discrimination, in the quarry from which the cubes are derived, of the true planes of tension, compression and stratification, which are not necessarily connected either with the horizontal or vertical division-planes in the stratum or with the lines of lamination or fissility in the specimen.

The relative weight of a volume of stone, taken in mass and including its empty cavities or "voids," the factor of practical importance to the builder, depends chiefly on mode of interlockment of its grains and consequent degree of consolidation, rather than on the specific gravity of its constituents. This becomes at once apparent by comparison of the specific gravities of the common minerals in building-stones and of the stones themselves, viz.:

Quartz	2·65	Sandstone	2·6
Feldspars	2·5–2·8	Limestone	2·6–2·8
Micas	2·7–3·2	Slate	2·5
Hornblende	3· –3·3	Granite	2·6–2·7
Calcite	2·5–2·8	Marble	2·6–2·8
Dolomite	2·8–2·9	Dolomite	2·8–2·95

The slight variations here stated, except in the rarer minerals, hornblende and iron-micas, show clearly that the actual weight of a definite bulk of stone depends almost entirely on the amount of its voids and of the cementing material which may occupy them.

II. COHERENCE.

Independently of the connection between grains of stone produced by interlockment, two modes of coherence prevail, each mainly characteristic of one or other of the two classes of building-stone, *cementation* and *molecular cohesion*.

(1) *Cementation*, mainly prevalent in the fragmental stones. The most common cementing materials in freestones are iron-oxides, clay and silt, but these are among the feeblest, except when uniformly diffused in minute films among closely abutting grains—the form in which, in the arts, even a feeble cement becomes tenacious, whether it be the mucilage of the stationer, the glue of the cabinet-maker, or the mortar of the mason. The cement is often unequally distributed, *e. g.*, in the sandstone of Corsehill, Scotland (*Fig. 18*), heaped together in the larger cavities, and, to a large extent, absent or scanty among the finer interstices where alone its binding power could be effective.

In other cases there is a great excess of cementing clay crowded into all the cavities, and even wedging apart the grains in thick plates, crusts and lumps, mixed with finer sand, often shown in the brownstone of Portland, Conn. (*Fig. 8*). The poorest of all cements are the kaolinic clays; better than these, the ferruginous clays* and the amorphous and granular iron and manganese-oxides, all of common occurrence. The last become powerful cements only when they occur in crystalline form, as fibrous films and crusts of magnetite, hematite, limonite, turgite and pyrolusite. Such sandstones with crystalline cement are not common, often irregularly tinged or blotched by ochreous clouds, not always freestones, and less popular on that account, but they are among the best of our building materials.

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*Through Dr. Heinrich Ries, of Cornell University, I am informed of the following experiment, stated to him by Prof. S. H. Babcock, upon the brownstone of Oswego, N. Y., a poorly cemented and friable sandstone, which contains as cement ferruginous clay in excessive amount, and which possesses a crushing strength of 2,400 pounds to the square inch. After baking a cube of this stone in a brick-kiln for the usual period, two or three weeks, it was found to possess a crushing strength of 12,000 pounds, evidently from conversion of its clay-cement into brick.

Fig. 7.—Biotitic Gneiss.—New York City.

Fig. 8.—Sandstone (Brownstone).—Portland, Conn.

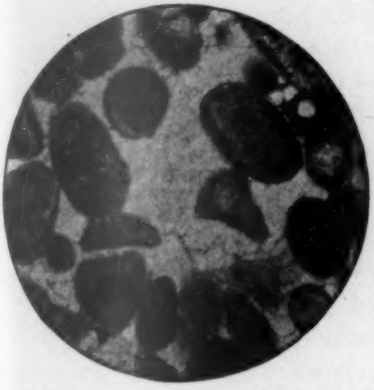

Fig. 9.—Oolitic Limestone.—Bedford, Ind.

Fig. 10.—Quartzitic Sandstone.—Potsdam, N. Y.

Fig. 11.—Shell-Limestone.—Lockport, N. Y.

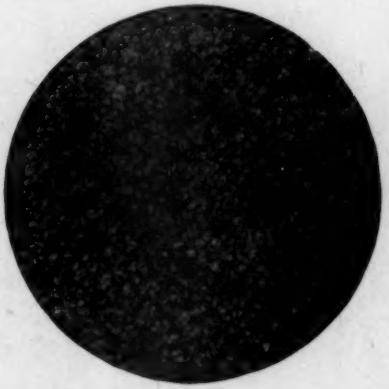

Fig. 12.—Limestone.—Radnor Station, Pa.

Plate B.

Fortunately, the lack of cementing power of the true clays is remedied, in many cases, by their marly character, and to this invisibly diffused content of lime-carbonate is due the credit ordinarily given to the visible kaolin and iron-oxides in the interstitial cement. When this is dissolved out by weathering the cementing clay softens, the stone becomes pulverulent and disintegrates into sand. Minute crystals of calcite have been occasionally detected in the cement of the Connecticut and New Jersey brownstones, and it is probable that magnesia and iron-carbonates also lend their aid.

Lime-carbonate, like iron-oxide, becomes a strong cement only when found in crystalline veinlets. Thus, the Caenstone or oolite of Southern Europe, the favorite building-stone used in the great cathedrals of the Old World, is a soft, granular, very cellular and earthy sponge. When introduced into the cities of the Eastern United States, its rapid disintegration astonished prominent architects who had been leaning upon European experience. Its preservation and survival for a short term of years were secured only by repeated coats of paint. From continuance of this absurdity we have since been saved by the recognition and introduction of the better class of so called oolitic limestones of our Western States. In these the rounded organisms (foraminifera) and tiny concretionary spherules and lenses may be but partially cemented together, the intervening cavities in large part unfilled and visible to the unaided eye (*Fig. 3*), and the crushing resistance only about 6,000 to 7,000 pounds to the square inch. But elsewhere in the same region the interstices of this rock, as at Bedford, Ind. (*Fig. 9*), though still larger, are completely occupied by calcite in crystalline veinlets, often pure and limpid; to their binding force, the great compactness of the stone, probable durability and high compressive resistance, 10,000 to 12,000 pounds to the inch, are mainly due.

The most powerful of all cements is silica, which in the form of compact crystalline quartz, binds together a large part of the otherwise loosely pulverulent sandstones of the Cambrian and Lower Silurian formations into solid quartz-

ites. From the point of strength and durability, these supply us with one of the most satisfactory building-stones, the quartzitic sandstones of the Northwest, of Lumberville and Mauch Chunk, Pa.,* and of Potsdam, N. Y. (*Fig. 10*). It can be readily dressed, it is true, only soon after extraction from the quarry; it quickly hardens by drying out of the quarry-sap, even during transportation to market; it cannot be treated as a freestone, and the building world usually rejects it and stones of its class (like the excellent Craigleith stone of Great Britain) as too hard and too costly for modern needs. Is it not a sorry matter that, not the pencil of the architect, nor the design of the engineer, nor even the true economy and interest of the builder are called on to-day to decide on the choice of the best stone, but the tenderness of the edge of the stonecutter's chisel?

The remarkable strength of a stone, like the one just described, is plainly due to the nature of its interstitial cement, rather than to that of the main material. The visitor to the great castle at Heidelberg, Germany, and also to a smaller, on the summit of the mountain across the Neckar, will notice, on examining the great piles of masonry blown up by the armies of Louis XIV, that the walls have fallen in solid masses without crumbling, the fractures cutting straight through both the stone blocks and their intervening seams of excellent mortar. In contrast with this, the frequent weakness of the natural cement among the grains of a stone is well disclosed in a thin section of Potsdam sandstone, in poorly consolidated form, from the region along the tributaries of the Upper Mississippi. In this arenaceous sandrock (*Fig. 4*) the grains are barely cemented together with a little iron oxide. The line of weakness will be recognized, in the crumbling thin section, by the divergence of the crack in and out around the grains of quartz, following the film of weak cement.

In the crystalline stones also, even the granites, there is good reason to suppose that some cement may be often partly concerned in their strength. One evidence of this is

* Hopkins, *op. cit.*, 86, 91.

the effervescence caused by application of an acid in many specimens, sometimes accompanied by loss of coherence and strength. This testifies to the diffusion of lime, magnesia and iron-carbonates through the interstices, though in forms rarely detected by microscopic examination. There is also significance within the coarser limestones (*Fig. 11*), marbles (*Fig. 17*), and granites (*Fig. 2*), whose grains may be an inch or more in diameter, in the delicate, light colored films and crusts of calcite, aragonite, hyalite, pyrolusite, etc., familiar to the mineralogist and petrographer. These become readily apparent to the naked eye by reflected light on the surfaces of opened fissures and cleavage-planes, though of course hardly distinguishable in stones of finer grain.

Again, we know that if the quarry-sap or natural interstitial juice of a building-stone is allowed to remain in a freshly quarried block, left exposed to the winter cold, its expansion by frost produces the "rifts" or "checks" with which the stone may become seamed and ruined. For this reason, as well as on account of the objectionable staining often produced by its evaporation, and even the surface disintegration of masonry sometimes caused in part by its efflorescent crusts, the quarry-water in building-stone may act as a source of injury. Yet, on the other hand, to this same evaporation the rapid and desirable hardening of the surface of many varieties of stone is indebted, after a short exposure to the air, either in hewn blocks or on the quarry-face.

Such facts indicate that the grains of even a crystalline building-stone owe their mutual coherence, and the rock its strength, in part to cementation by films of solid matter deposited in the interstices from infiltrating solutions or quarry-sap. Is it not surprising to remember that as yet we know nothing with certainty concerning the varying nature of this important liquid—often the very life-blood of a valuable building-stone! We may conjecture, indeed, with high probability that, in the deposited films, lime, magnesia, iron and manganese-carbonates and iron and manganese-oxides are common, that lime-sulphate often occurs, and that sili-

cates of soda, potassa, lime, magnesia and other bases, and even dissolved colloid silicic acid, crystallizing as quartz or amorphous in the form of chalcedony or hyalite, also generally serves in the office of cementation. Thus the dendritic and concretionary films, which on joints, seams and fissure-planes supply the rare curiosities of crystallization, the charming arborescent or stellated *bric-a-brac* of the mineral collector—rock crystal, opal, hyalite, aragonite, siderite, limonite, pyrolusite, zeolites, serpentine, epidote, etc.—offer, in the microscopic forms of their dissemination, humble and essential service in welding together both the strata and the constituent grains of most kinds of stone.

(2) *Molecular Cohesion.*—It is in the crystalline stones chiefly that coherence between the grains is greatly increased by another physical force, molecular cohesion, that which exists between surfaces of all solids pressed into intimate contact. With this force we are familiar in the close coherence of smooth surfaces of glass sheets, especially of polished plate-glass. In consequence of the tremendous force here involved, that of capillary adhesion, such surfaces may cohere so strongly that, on application of sufficient pressure for detachment, the very surfaces themselves may be torn away. This cohesion is reinforced to a small extent, about 16 pounds to the square inch, by atmospheric pressure. A block of a crystalline stone comprises an innumerable quantity of minute planes in close adherence; especially is this the case in those sheared forms of rock in which original coarse grains or crystals have been crushed into plates, whose small cleavage-faces, absolutely clean at the moment of splitting apart, have been at once squeezed and welded together under intense pressure. It is probable that increased compressive strength may accompany increasing fineness of grain, for instance, in series of granites, from coarse granite at one extreme (as in *Fig. 2*), through brecciated forms down to a fine granite, granite-porphyry or felsite, at the other; this result, suggested by study of reported tests, may have been produced not only by more intimate interlockment of grains, but by the subtle physical force of capillary adhesion.

The marbles and dolomites exhibit the same congeries of tangent planes and correspondingly high compressive strength. The flexibility of these stones, many instances of which I have elsewhere recorded,* and their actual plasticity, as confirmed by the recent interesting experiments on artificial compression of marbles, by Profs. F. D. Adams and J. T. Nicholson† at McGill University, Montreal, are accompanied in nature, during compression, shearing and flow of the stone material, by no tendency to loss in coherence and strength. This is the more strange, since the internal motion implies a sliding or play of the grains to some extent over each other, with sufficient friction and attrition, in cases where solution and recrystallization have not ensued, to have produced a partial rounding of many grains sometimes distinguished in a thin section of dolomite or marble, a structural condition in which there is clear evidence of imperfect interlockment and of little possible cementation. Yet there often remains an enormous compressive strength, which, in some limestones and dolomites, reaches 25,000 pounds to the square inch, beyond that of most granites.‡ Over this puzzling anomaly an English writer thus expresses his views: "It is not merely the nature of the constituents or their mechanical mixture that gives dolomite its good qualities; there is some peculiarity in the crystallization which is all important. In the formation of dolomites, some peculiar combination takes place between the molecules of each substance; they possess some inherent power by which the invisible or minutest particles intermix or unite with each other so intimately as to be inseparable by mechanical means."§ In my opinion, it is not the chemical combination here pointed out which is concerned in resistance to crushing, but the peculiarity in mechanical mixture or texture, in

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* Tenth Census of U. S. (1880), X, Report on Building-Stones, 366–367. See also observations of A. Winslow on the bent marble slabs in a cemetery (*Am. J. Sci.* (3), XLIII (1892), 133).

† Stone, XVI (1898), 349, and Science, VII (1898), 82–83.

‡ N. H. Winchell, Geol. Minn., Final Rep., I (1884), 156.

§ "Notes on Building Construction," So. Kensington Series, Pt. III, 58.

both marbles and dolomites, resulting in surface cohesion of an enormous number of minute crystalline plates.*

Even in fragmental stones, the same increase of strength with multiplication of contact-planes is often indicated, especially in the more finely brecciated forms of limestones, brecciated sandstones, quartzites and flags (*Fig. 6*). In the coarser limestones, such as that of Lockport, N. Y. (*Fig. 11*), originally brecciated aggregates of broken fossils, an inferiority in strength and durability is manifest, which seems to be caused chiefly by imperfect coherence of these grains with rounded outlines, among which fine cracks consequently run in an interlaced system; the weakness may be increased by the coarse cleavage-structure commonly developed within the grains themselves.

In the finer semi-crystalline limestones, like that of Cream Valley, near Radnor Station, Pa. (*Fig. 12*), the important relationship between size of grain in a stone and its strength (and probable durability) is presented in the multiplication of facets. In a similar minutely crystallized limestone of Lake Champlain, N. Y., the crushing resistance reaches 25,000 pounds to the square inch.

An important exception occurs, however, to connection of durability with minuteness of texture, in limestone or dolomite, in intermixture of organic and aluminous matters, especially bluish clay. This constituent ordinarily occurs in the form of thin shaly layers, alternating with others of purer limestone. Even though the compressive strength of the entire stone may reach 20,000 pounds to the inch "on bed," the eager absorption of moisture by the clay and oxidation of its iron-protoxide produce a softening, cracking and disintegration, hastened by alternations of soaking and drying, of freezing and thawing, which render these common

* From the retention of form by the grains of this mineral, in spite of the pressures generated during dynamic metamorphism, as shown by their sharply defined polygonal outlines, in a thin section of dolomite-marble under the microscope, Vogt concludes "that the extraordinarily high compressive resistance displayed by dolomite-marble is probably connected with the fact that dolomite possesses a very high power of resistance to mechanical deformation."—*Loc. cit.*, p. 16.

argillaceous varieties of limestone and dolomite the poorest of building-stones.

The fine granulation of a stone, also, may favor absorption of moisture, introduction of corrosive vapors and liquids, crumbling and exfoliation, under the attack of the weather and frost, on account of the more ready loosening and displacement of successive fine grains; partly because interlockment is less intricate in fine than in coarse grains, and partly through the action of capillary interstices, the grains in some stones not lying in intimate contact.*

The absorption-coefficient of stone toward liquids depends partly on the forms and abundance of its interstices,† and partly on the porosity and abundance of the natural cement which may occupy them. As to the former, it is important, for my present purpose, to distinguish two classes of interstices,‡ well shown, from their equal distribution, in the sandstone (grès) of Beauchamps, France (*Fig. 13*). (1) The fine *seams*, which make up the close network of intersecting fissures, cracks or contact-surfaces in and between the grains or crystals; these are largely of capillary

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* From the study of churches, etc., in Northern and Western Norway, even six or seven centuries old, it has been ascertained that massive coarse-grained (regional metamorphic) marble is better suited for use in the open air than the compact or fine-grained Carrara marble, on account of the much smaller surface exposed to attack among its coarse grains.—Vogt, *loc. cit.*, 49.

† The openings of rocks in general, viz., tubes and sheet-passages (such as those furnished by faults, joints, etc.), have been thus classified (C. R. Van Hise, Bull. Geol. Soc. Am., IX (1898), 272):

Larger than capillary,	Tubes, diameter over 0·508 millimeter. Sheet passages, width over 0·254 millimeter. Water-movement, by ordinary laws of hydrostatics.
Capillary	Tubes, less than 0·508 millimeter. Sheet passages, less than 0·254 millimeter. Water movement, by laws of capillary flow.
Sub-capillary . . .	In which molecular attraction of solid material extends from wall to wall. Tubes, less than 0·002 millimeter. Sheet passages, less than 0·001 millimeter.

‡ "A Study of the New York Obelisk as a Decayed Boulder," Annals N. Y. Acad. Sci., VIII (1893), 158, 159.

breadth, and, in part, cross the grains themselves in the finest cleavage-clefts, and in fissures generated by crushing. (2) The angular *pores*, or cavities, in part, tubules and widened cracks, occurring at intersections of the seams, often of notable volume up to that of an actual cellular structure, in the more loosely compacted and arenaceous kinds of stone, especially sandstone and cellular limestone (*Figs. 3* and *9*).

Where a cement occurs, it occupies chiefly the pores, in amorphous, finely granular or crypto-crystalline, closely packed masses (*Figs. 8* and *5* and *Fig. 14*), many seams remaining empty or only coated in parts by cement in thinnest films (*Figs. 4* and *18*). The absorbent capacity of stone toward a liquid is affected chiefly by the volume of permeable pores and seams, and diminished by the amount of obstructing cement. Rapidity of absorption depends upon the area affording capillary action; if the interstices are free from cement, largely upon the seams; if a spongy cement is present, upon its additional though slower increment of capillary force within the pores as well as the seams.

The destructive expansion, caused by ice-films within a stone, is due in my opinion mainly to the large ice-flakes occupying deeper clefts and pores than to the minute films occupying superficial seams; on the principle of the more destructive efficiency of the swollen ice confined within the expanded part of a bottle than that of the slender ice-cylinder which is thrust out of its narrow neck.

If these conclusions are correct as to the differing influence of pores and of seams upon the absorption-coefficient of stone and upon its mode of disintegration by frost, the methods of testing absorption should be so modified as to make this interstitial distinction. Such a modification I believe to be approximately practicable. In any case the difficulty of disentangling minute air-bubbles from the complicate network of capillary passages, if once partly occupied by water, should show the imperfection of the common method of determining the saturation-coefficient of stone by immersing the test-cube in water or covering it at once with

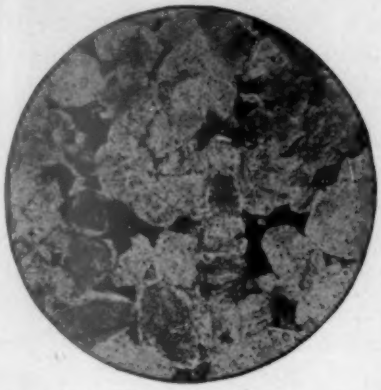

Fig. 13.—Quartz Sandstone.—Beauchamps, France.

Fig. 14.—Sandstone (Brownstone), Paterson, N. J.

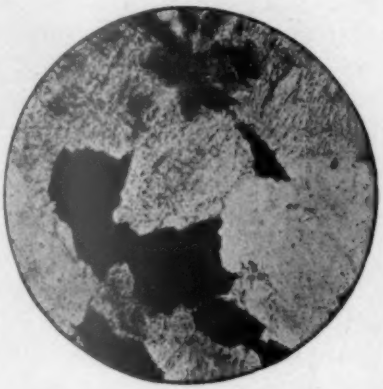

Fig 15.—Granite.—St. Cloud, Minn.

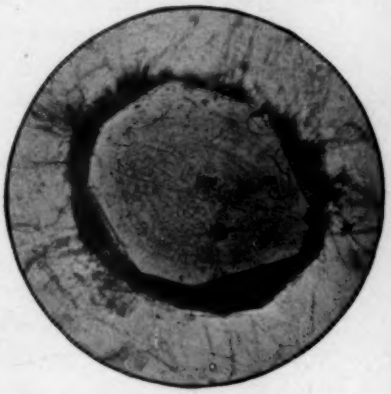

Fig. 16.—Garnet in Muscovite.—Wieser Mt., Id.

Fig. 17.—Dolomite-Marble.—Tuckahoe, N. Y.

Fig. 18.—Sandstone.—Corsehill, Scotland.

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Plate C.

water; the preferable method is by soaking upward from a wet tile at the beginning of the test.*

In certain kinds of stone, a tendency to partial solution in atmospheric waters is closely connected with their lack of coherence and durability. The most prominent example is presented in ordinary limestone, consisting of imperfectly crystallized or amorphous carbonate of lime, the most soluble form of that substance, and that too in granular or earthy condition and thus offering the largest possible area for permeation and attack by a solvent. The vast amount of surface and subterranean erosion and solution, carried on in all limestone regions, is too well known to need any present description.

The earthy magnesian limestones offer as little resistance to erosion. But with crystalline forms, the marbles and dolomites, the extent of solution and erosion becomes greatly diminished and generally quite superficial.

An exception occurs where the solvent action has become reinforced by increased acidity, as in rain-waters of city atmospheres polluted by smoke from combustion of pyritous coal. These have been found to contain sulphuric acid, to the gallon, in London, 1·43 grains; Liverpool, 2·77; Manchester, 2·91, and New York, 4·85. The last figure is founded on a single determination for forty-one days,† and it has been estimated by the same investigator that the 4,500,000 tons of coal annually burned in New York City discharge into the air 78,750 tons of this acid. However, an impression prevails that the increased attack upon the building-stones of a large manufacturing city is partly due to increased proportions of carbonic acid in its atmosphere. In behalf of this opinion, reference has been made‡ to the following proportions of that gas in 1,000,000 parts of the air in various cities, viz.: Liège, 335; Boston, 385; Cambridge, 337; Washington, 387 to 448; Berlin, 390 to 450; Manchester, 442. However, as the mean content of carbonic acid in the gen-

*"A Study of the N. Y. Obelisk," 159–160.

†T. Egleston, "The Cause of Decay of Building-Stone," *Am. Arch.* (1885), 5.

‡G. P. Merrill, *op. cit.*, 359, and Vogt, *loc. cit.*, 47.

eral atmosphere is accepted as about 400 parts, with variation from 300 to 620, according to different authors (and even to 1,110 on Mt. Blanc, according to Frankland), the evidence is against its concentration, except in barely perceptible proportion, in the open air of any city. Nevertheless, during certain foggy conditions of the atmosphere, when the condensed vapors of a city lie over it in an undisturbed bank, it may yet be found that carbonic acid is associated with the other acids in increased proportions at such periods, in both the air and the rain waters, to assist in the corrosion of stone.

In the sandstones, the general marly constitution of the cement or dissemination of iron-carbonate and the loose spongy texture of the stone supply conditions specially favorable for solution and disintegration, *e. g.*, in poor varieties of brownstone, such as one from Paterson, N. J. (*Fig. 14*).

In granites and stones of that class, the minerals with iron partly in ferrous condition, feldspars, iron-micas, chlorite and hornblende, are subject to notable amount of solution, as well as of attack and injury in other ways, by the agencies of weathering. This is especially marked by the quick discoloration and deep decay of the tremolite, rich in ferrous oxide, which abounds in the coarse dolomites of our Eastern States.

The process of solution of constituents during submersion of stone, especially that by the action of sea-water, is of important concern to engineers, as affecting both foundations and lower courses of masonry in piers and abutments of bridges, docks, light-houses, fortifications, etc., along the sea-coast. Yet on this subject there appears to be no record of experimental investigation, and we have no definite information whatever. For example, in the attack of sea-water on the mortar or other artificial cement between blocks of stone, on the marly natural cement in the interstices of a sandstone, and on the general calcareous material of a limestone or marble, may we assume that the chief reaction is the production of calcium sulphate as a protective coating, or that continuous solution, corrosion and destruction of the material ensues?

As to the resistance of coherence in building-stone to weathering, the methods of trial or test are very numerous and belong to two classes, artificial and natural.

An artificial method, if thoroughly satisfactory, must cover all the complex processes by which the disintegration of stone is ordinarily effected, viz.: the solution of part of its ingredients by circulation of sap through its interstices, the swelling and splitting of others by absorption of oxygen and water, and the mechanical rending apart of superficial grains by alternations of temperature and by expansion of ice-films. It must be further adapted to the widely different degrees to which each of these three processes—solution, absorption and disruption—affects the different kinds of stone. Thus a method founded on solution (such as treatment of cubes of stone by carbonic acid or by weak hydrochloric acid), or on oxidation and solution (as by exposure to acid fumes) entirely neglects the other process, and must be worthless in application to the stones of entire solubility, the limestones, dolomites and marbles. A method only efficient in mechanical disintegration (such as exposure of stone-cubes to alternations of freezing and thawing) is equally imperfect, especially with varieties whose cement or whose grains are peculiarly subject to solution or to chemical decomposition. Even in more complex methods of trial (such as Brard's, with sodium-sulphate), in which disruption is produced by means of the crystallizing salt, and, as well, some indefinite degree of solution, none of the subtle attack of chemical reaction is well considered. It is obviously doubtful if any artificial method of universal application can ever be devised for exact determination of degree of coherence in rock-grains under atmospheric attack. Yet we may hope for the development of artificial methods of trial, of satisfactory application to special kinds of building-stone, after these methods have been thoroughly *standardized*, in comparison with the natural evidences of durability and with the results of general tests of that property on a full series of the important building-stones of the world.

The unsatisfactory character of even the artificial methods

of limited application has frequently led to their rejection, in recent years, in favor of the natural methods.

To one of these, the study of natural outcrops and of ancient artificial exposures of a stone in vicinity of its quarry, with careful observation of both character and depth of its weathering, decided preference has been often expressed by writers on the subject. But this natural method also is attended by special difficulties, which it may be well to illustrate by recent observations at Tuckahoe, N. Y.

The dolomite-marble of that region (*Fig. 17*) occupies only the eroded bottoms of the narrow valleys. Abundant outcrops of that rock occur along the edges of the quarries, covered by a crust of deeply decayed and discolored material, often passing into dolomitic sand. Yet this apparent evidence of the mode and extent of its weathering cannot be fairly accepted, since all these present outcrops merely indicate the recent stripping of an ancient surface of dolomite, long subjected to the action of peaty waters, rich in organic acids, derived from swamps, bogs and accumulations of humus which once overlay the bottoms and slopes of all these valleys. In evidence of true weathering, not a single satisfactory outcrop was found.

Another exposure of deeply decayed gneiss in a cross-valley, running east and west, possessed as little significance, in comparison with other beds of fresh gneiss outcropping on the adjoining hillside. The former merely represented a remnant of the ancient continental surface decayed during the vast pre-Glacial Period; its escape from removal by glaciation was due to its sheltered situation.*

* In the region south of the glaciated belt it is obvious that still greater uncertainty attends this method of diagnosis. During the interval between the reading and publication of this paper, the following good illustration of this point has been put on record: "Investigation at the quarries, where a considerable depth of decomposed rock is seen to overlie the more marketable material, suggests the suspicion that the Port Deposit granite will not withstand atmospheric agencies for any great period of time. This deceptive appearance arises from the fact that the crystalline rocks southward from Philadelphia have not been scoured and cleaned by the action of glacial ice as in more northern latitudes. Thus the overlying waste represents the decomposed products of several geological epochs, perhaps reaching back as far as Cretaceous time."—E. B. Mathews, Maryland Geol. Survey, II (1898), 145.

Again, at Sutherland Falls, Vt., the perfectly fresh unstained surface of a white marble outcrop bore equally untrustworthy evidence in its behalf in comparison with the rusty eroded crust of another bed on a hill-top above. The high glacial polish and sharp striæ upon the former proved that it had not been long uncovered from the heavy protecting coat of glacial clay common in the vicinity.

It appears, therefore, that this natural method is attended by as many difficulties as any of the artificial, and that it calls for as much exercise of careful judgment in consideration of the past history of any exposed outcrop of rock, whether it has been subjected, how long and how recently, to exposure to weathering; to that excessive trial during pre-Glacial time; or to the subsequent planing and cleaning by the Continental Glacier; or to long protection by loose porous or by compact overlying deposits of unknown thickness; or to attack by acid swamp-waters; or to frequent cleansing by heavy rainfalls, as on mountain-tops, by local streams or by the higher tides or storm-waves of neighboring waters; or to the attrition of sands swept over by desert-winds; or to artificial protection or uncovering, as by roadsides, within the historic period.

The other natural method of determining the resistance of a stone to weathering—and one which, when available, under known conditions and of sufficient antiquity, may be, perhaps, the most satisfactory of all—consists in the study of weathered surfaces of ancient stone buildings and monuments. Yet this, too, may easily lead to error, unless due attention be paid to the many varying influences which may have affected the exposed surfaces in question; subjection to dampness, to street dust, to soil acids, to acid vapors, etc., within a few feet of the ground, or to a purer air at a higher level; to the afternoon sun, to continued frost or to frequent thaws, to certain prevailing rains and winds on the different sides of a building; to the purer atmosphere of a rural or suburban locality, to the air of a city tainted by acid vapors, chimney-soot or fumes from factories; to salt fogs from the sea, flying sand from beaches or arid deserts, the action of lichens and other vegetable growths, protec-

tion by foliage, the influence of the original dressing of the masonry, especially on well tooled or bush-hammered surfaces, etc.

It is apparent, therefore, that the elements of strength, on which the coherence of the grains of stone depends, in resistance to weathering, are so varied, that with many kinds no single known method, artificial or natural, can be relied upon without question and without confirmation. We yet need to seek for light through comparison of results from all promising methods of possible application, and often to gratefully accept even an approximation to the truth.

[*To be concluded.*]

Stated Meeting, Wednesday, February 8, 1899.

SUBTERRANEAN ICE DEPOSITS IN AMERICA.*

By Edwin Swift Balch.

The whole subject of subterranean ice is so bound up with questions of temperature that it seems well to say a few preliminary words about underground temperatures in general. Underground temperatures may best be studied under three heads: the normal, the super-normal and the sub-normal. The normal or ordinary temperatures scarcely change the whole year round. There is a superficial layer of soil or rock, of but very slight depth, which is affected by the outside temperatures; beneath this there is usually a layer, the temperature of which is about that of the mean annual temperature of the locality; below this the temperatures increase slowly with increasing depth below the surface. This increase may be roughly stated as about 1° C. for every 32 meters in depth. Super-normal temperatures at or near the surface are very rare, and are due to special causes. Thus, there are a few caves which have temperatures much above the mean annual temperature of their locality. In such cases, the heat is generally due to the presence of hot

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springs or to volcanic action in the immediate neighborhood.* Sub-normal temperatures in the superficial layer are rare, but less so than super-normal temperatures. These temperatures may be abnormally low without descending to the freezing-point. Sometimes, however, they are so low as to be accompanied by the formation of ice.

For some years I have been collecting all the data I could find about subterranean ice deposits in America. Scientific journals, one or two books of travels, and cuttings from local newspapers, have furnished information about a number of places, and correspondence with persons residing in their neighborhood has given more. My notes include over fifty localities ranging from Greenland to Tierra del Fuego. Much of this information comes from the reports of trained observers, such, for instance, as the paper of Lieutenant Cantwell, describing the ice cliffs on the Kowak River. About the accuracy of most of the information I feel but little doubt, except in regard to the measurements given, concerning which there is a tendency to report things underground as much larger than they really are.

On the west coast of Greenland a number of buried glaciers are reported.† These seem to occur when a glacier finds its outlet in the sea and for some reason stops flowing. Then some of the Arctic mosses and lichens, which flourish in spite of the cold, gradually make their way over the ice, first in thin layers, later in thick masses, the young plants trampling down the older ones until the latter turn to a rich mould. The seeds of grasses and flowers find their way to this until the whole plateau becomes a garden of green, gold and white.

Much frozen soil is found in Alaska. Prof. Israel C. Russell saw many strata of ice in the banks of the Yukon and he says that strata over 30 meters thick have been found. Much of the Klondike country is frozen down to bed rock, 8 or 10 meters deep. In this case the miners are said to cut off the moss with a shovel, and then to build

* F. Kraus, *Höhlenkunde*, p. 86.
† W. E. Meehan, *Philadelphia Ledger*, 1896.

a fire which thaws out the ground for 5 or 10 centimeters. They dig this out and then start another fire and continue the process. At the other end of the continent, in Tierra del Fuego, ice and lava are said to be found inter-stratified for a great depth, each winter's snow being covered by a new lava sheet. On Chimborazo also, Humboldt says that enormous heaps of ice are found covered with sand and far below the inferior limit of the perpetual snows.

In our Western States there are several caves which retain ice, and which are of considerably larger proportions than any in the East,* and there is no doubt that more will be discovered in the future. Places where ice remains, whether caves or not, are reported from Washington, Oregon, California, Montana,† Wyoming, Colorado and Arizona. A particularly interesting place in the State last named was brought to my notice by the distinguished archæologist, Mr. Frank Hamilton Cushing. It is a cleft in a lava bed, which, being roofed at the further end, might be described as a cave. In this the ice remains until June or July, much later than anywhere else in the neighborhood. The Zuni Indians have a mystical feeling about this, calling the ice the breath of the gods; the snow they consider a sort of down. The region is very arid, and water very precious, to which fact the association of the supernatural with the occurrence of snow and ice among the Indians may be explained.

In the States east of the Rockies some thirty-five subterranean ice deposits are known—in Maine, New Hamp-

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* One of these is in Washington. It is a lava cave, and is 56 kilometers from the mouth of the White Salmon River. Described by R. W. Raymond, *Overland Monthly*, November 3, 1869, p. 421. Another is on Cow Mountain, near Cripple Creek, Col.

† Mr. Robert Butler, of San Jose, Cal., wrote to me that he had examined a glacière cave and a freezing well in Montana, where such wells are not uncommon. The people in the neighborhood think the ice forms in summer. Mr. Butler investigated the question of cold-air draughts coming from these glacières. He found that, on rapidly walking into them on a hot day, the same sensation was produced as though one were standing still and the air were in motion. He also satisfied himself that, as far as he had observed, the ice was formed by no other cause than the natural cold of winter.

THE BLUFF AT DECORAH, IOWA. LOCATION OF CAVE ABOVE WHITE CROSS. (Photo. by Mr. A. F. Kovarik.)

shire, Vermont, Massachusetts, Connecticut, New York, Pennsylvania, Virginia, Indiana, Missouri and Iowa. The most southerly of these is in about 37° north latitude. The deposits in Arizona, which are yet further south, are at a much greater altitude.

Four of these only may properly be called caves. These are at Manchester, Vt., Ellenville, N. Y., Farrandsville, Pa., and Decorah, Ia. The little cave near Manchester is in a marble formation, and, so far as I know, it is the only marble cave in the world where abnormally low temperatures have been found. On the 5th of July, 1898, there was plenty of snow in it, but nothing that would strictly be defined as ice.

At Decorah, Ia., is a little cave or limestone fissure on the banks of the Iowa River. It is quite famous because the capillary theory—that ice might be formed by pressure on the water dripping through rock cracks—was formulated to explain it. On the 30th of September, 1898, there was no ice in it, and the temperatures were normal. Neither were there any tiny tubular fissures visible, but instead of these, there were quantities of fossils.*

Near Ellenville, N. Y., is a cave—or perhaps more correctly a gorge, as it is minus a roof—which is the largest natural refrigerator in the Eastern United States. Several friends of mine have found snow and ice in it in past years in July and August. Last year, on the 9th of October, neither snow nor ice was present, and the temperatures were only slightly below that of the outside air in the shade.

In Clinton County, Pa., on the banks of the Susquehanna River, opposite to the village of Farrandsville, is a mite of a cave.† It can only be entered for about 2 meters, although there are several cracks leading further into the rocks. The postmaster and the railroad agent at Farrandsville assured

* Mr. Alois F. Kovarik, of the Decorah Institute, published a valuable series of observations about the Decorah Cave, in the *Scientific American Supplement*, No. 1195, November 26, 1898. He thinks that the cold of winter is the source of cold.

† This could also be described as a windhole.

me that ice was never visible there in winter, but that it was found there from April, usually all through the summer months. On October 11th, there was no ice in sight, but after fifteen minutes' exposure, the thermometer dropped to 6° C., an abnormal result, showing, in my opinion, the presence of ice further in. The rocks also were abnormally cold.

Of rock gorges which act as refrigerators I have seen three in the Eastern United States. One is the, so-called, Ice Glen at Stockbridge, Mass. I was told that ice remained there later than elsewhere in the neighborhood, sometimes as late as May. On the 3d of July there were no trace of ice or snow, and the temperatures were normal.

There is a great gorge near Randolph, N. H., north of the Presidential Range, between Crescent and Black Mountains. This is called the Ice Gulch. The sides are quite sheer in many places, and the bottom is choked with an accumulation of boulders. Among these there was a small quantity of ice in one or two places on the 11th of August last. This ice was unusual in formation, neither solid nor prismatic, but full of air bubbles. It crumbled away in small pieces under the teeth.

In the Presidential Range itself is the great King's Ravine, on Mount Adams. The bottom is covered with huge boulders, and among these, some years ago at the end of September, there was plenty of prismatic ice.

There are a number of rock taluses in the Appalachians, where ice is found. One of these is on Lower Ausable Pond, in the Adirondacks, at the north base of Mount Sébille or Colvin. It is a huge talus of great Laurentian (?) boulders, among which are numerous hollows, which might by courtesy be called caves. On the 12th of July, Mr. E. I. H. Howell went with me to this spot, and in three hollows we found ice, in two of these places in considerable quantities. Mr. Howell has been repeatedly at this spot during past summers and always found ice, so it must be considered a perennial glacière.

Two days later, on the indications of Mr. Otis, the chief guide of the Adirondack Reserve, I explored the south talus of the Giant of the Valley. In two places about 1 kilometer

apart, and in each case in hollows among the boulders there was plenty of ice. I did not follow the talus throughout its whole extent, as the walking was fearfully bad, but apparently ice might be expected anywhere, as I found it at once at both places I inspected. One mass was certainly 5 or 6 meters long by 2 in width and 1 in depth. The ice was very pure, hard and non-prismatic. In one of the hollows, where there was only a little ice, the thermometer registered 6° C. after fifteen minutes' exposure, about 1 meter from the outside, and about 1 meter from the same spot in the shade of a tree, it registered 26° C., a difference of 20° C. within less than 2 meters.

Near Rumney, N. H., is a boulder talus where Mr. John Ritchie, Jr., Secretary of the Appalachian Mountain Club, of Boston, some years ago found ice in August. The Sheriff of Rumney accompanied me to this place, and said that ice was generally abundant there in summer. On the 18th of August we found none and the temperatures normal.

At Watertown, N. Y., under the tracks of the New York Central Railroad, are some rock cracks, in front of which cellars have been built, and these are used to store beer barrels. On the 12th of September there was no ice in the cracks, and the lessor of the cellars told me it had all melted away early this summer, on account of the great heat. Near Watertown is the picnic ground of Glen Park, where there is a hollow or rock basin, where ice and snow sometimes lie over until July. There are cracks in the rock sides of this hollow, in which ice remains over near the mouth, but it is not found any distance within.

An hour on foot to the north of the Pennsylvania Railroad Station of Spruce Creek, Huntingdon County, Pa., at the base of the Tussey Mountain, is a great talus of broken (sandstone ?) rock. It is some 150 meters long and 30 meters high. At the base of this talus are some small pits which are said to have been dug by farmers and which act as natural ice-houses. In these pits, on the 5th of October last, I could see my breath distinctly, and on the talus the air was much colder than anywhere around it. I thought I saw ice far in among the rocks, but I could not be sure. There must surely

have been some, however, for the temperature was abnormally cold.

Freezing wells are a form of natural refrigerator not uncommon in the Eastern United States. One of these was said to be at Owego, N. Y. I visited the place on the 23d of last June, and found that the well had existed, but that it had been blocked up many years ago. Mr. Preston, who had lived beside the well all his life, informed me that he had more than once been down in it, that it passed first through a layer of sand, then through a layer of gravel, and that he had seen the sides covered with ice, and that ice had sometimes filled it solid about half-way up.

At Brandon, Vt., is another freezing well. This has been described in the *Geology of Vermont* as containing ice as late as July. The owner of the well assured me that it froze solid every winter. I was there on the 7th of July, and twice lowered a thermometer, and each time, after ten minutes, it registered only 13° C., a strictly normal temperature.

At Decorah, Ia., also, there is a well which is reported as freezing up every winter. At the end of September there was no ice in it.

I wish now to make a brief résumé of the chief points which these ice deposits, and a certain number which I saw in Europe in 1897, have suggested to me, since I delivered a lecture on "Ice Caves" before the Franklin Institute two years ago.*

Natural refrigerators fall under something like five main heads:

(1) Gullies and troughs where ice remains.

(2) Boulder taluses containing ice.

(3) Ice sheets overlaid by soil or rocks.

(4) Wells, mines and tunnels which freeze at times.

(5) Caves with abnormally low temperatures and mostly containing ice.

For four of these five different rock formations, as far as they are connected with ice, we have only two terms in

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English and those the entirely incorrect ones of "ice cave" and "ice gorge," and the more I have followed up the subject, the more do those names seem misnomers to me. We say "limestone cave" or "lava cave" and in the same way we should say "ice cave" when the sides and roof of a cave are formed of ice; that is, we should reserve the term for the hollows at the ends of glaciers whence the glacier waters make their exit. Curiously enough, the Germans use the same inaccurate phraseology as ourselves, and there is only one term which is really generic, namely, the French *glacière naturelle*. This is comprehensive and accurate, embracing the geological structure and suggesting the mode of formation of the ice. In my opinion we should either adopt the French *glacière* or use its English equivalent, "natural refrigerator."

The next point I wish to touch on, relates to the mode of formation of the ice of these glacières. In every case glacières seem to me to be purely refrigerators, which preserve the supplies of ice and snow stored in them during the winter. They all follow the same general laws as to their origin, modified only in slight degree according to the varying natural conditions of the place, such as the water-supply, or the protection from sun or wind, or the thickness of the overhead rocks, or the altitude or latitude. I cannot see that there is anything very remarkable about the fact that the cold of winter is able to penetrate and make itself felt sometimes for a very slight depth in the earth's crust, a depth so far as yet known never exceeding 150 meters. And it seems to me, that glacières only emphasize a law of nature which has doubtless been formulated many times in connection with springs and phreatic waters, and that is, that where we find very cold waters underground, we may be sure that they have penetrated from the outside.

The excessively hot summer of 1898 has furnished some valuable proofs of the fact that the cold of winter is the originator of the ice, and the heat of summer its destroyer. At Rumney, for instance, where there is generally ice in August, there was none last year. At Ellenville, I was told there was always ice in the cave. Yet I found none, and

the temperature was normal, and as far as I could learn this was something never known before.

The fact that there was no ice last summer at the freezing wells of Brandon or Decorah, is a proof that natural refrigerators have nothing to do with a glacial period. This point was settled about caves long ago, but it might have been claimed to hold about freezing wells, as we cannot be sure how long a time the gravel beds they are dug in had been frozen. But freezing wells evidently do not depart materially in their actions from other glacières, since there was no ice at the freezing wells of Brandon or Decorah last summer, and the testimony shows conclusively that there was plenty of it last winter and that there will be plenty this winter. Any lingering doubts I may have had about the capillary theory—that is, of the ice forming by pressure—have been dispelled by visiting the cave at Decorah, where there were none of the supposed hair fissures, and which is not especially different from similar caves in Europe. If, as is sometimes claimed, the ice is formed by evaporation or by expansion of the air, and that these factors are most active when the weather is hottest, then the past summer afforded the best possible conditions for their demonstration, and there should have been ice at Ellenville and Decorah.

The subject of evaporation is closely connected with a very important point about glacières, and that is subterranean draughts and the movements of air. Believing, as I do, that it is the cold air of winter which causes the ice, it is necessary to consider its action. First, there is a form of subterranean hollow, where there are at least two openings, of which one is higher than the other. In these there are almost always draughts whose direction varies according to the outside temperature. When the air within is colder than that of the air outside, then by its own weight the air within the cave flows out at the lower opening. When, on the contrary, the air within is warmer than the air outside, then this warmer inside air rises and leaves the cave at the upper opening, and is, of course, replaced by an equal volume of cold outside air flowing in at the

lower opening. This is the phenomenon of blowing caves or windholes, and when ice is found in them, it is always at the lower end, as it is at that end that the cold air enters, and it is also to that end that water gravitates. Instead of the ice in these windholes being formed by evaporation, it seems to me that when the air flows out at the lower end, it must then have a tendency to vaporize the ice and carry it away as moisture.

Then there is a class of caves where there is only one entrance and where the body of the cave is lower than the entrance. In these the air in summer is apparently stagnant, and hence they have been called static caves. The name is not descriptive, however, for in cold weather the heavy winter air sinks into these caves and displaces the air within, of course setting up some motion. Even in summer I question whether the air is always as stagnant as it seems. At the Glacière de Saint-Georges, in the Swiss Jura, there is the entrance to the cave, and at one end of the cave there is an opening in the roof. In August, 1897, the air seemed perfectly still within the cave on the ice floor, yet standing nearly under the hole in the roof, I found that the smoke of my cigar rose very rapidly straight up; it seemed almost to be drawn or sucked up from above, and certainly the air was not stagnant at that spot. There can be no question, it seems to me, that it is the movement of the heavy cold air of winter downward into these caves which supplies the cold which forms the ice in them.

Although I disbelieve that the evaporation in windholes is ever strong enough to cause ice to form, yet I have no doubt whatever, that in caves with a temperature some degrees above freezing-point, when there is either running water or strong drips, evaporation may be, and sometimes undoubtedly is, a factor in lowering the temperature somewhat;* and as in some windholes there is sometimes moisture on the rock surfaces where the air current passes,

* This is also the opinion of M. E. A. Martel. *Les Abimes*, Paris, 1894, p. 564, and *Mémoires de la Société de Spéléologie*, 1897.

the evaporation from these surfaces doubtless sometimes lowers the temperature of the air currents appreciably.*

There is, however, no reason to think that evaporation ever lowers the temperature of air currents below freezing-point. Taking all the facts which I have myself observed, and all that I have read in the reports of others, my conclusion is that we have absolutely no proof that underground evaporation is ever effective in producing ice.

A good deal of confusion has been occasioned by the nomenclature of these caves. One kind has been termed *windröhren*, or windholes or blowing caves; the other, *eishöhlen*, or ice caves or static caves. The important point, however, in this connection is that sometimes ice occurs in both these classes of caves and sometimes it does not. I wish to repeat that the only rational terminology is the French one, to speak of any place where there is ice underground as a glacière or refrigerator. If there are two openings at different altitudes, and hence distinct draughts, then we have a windhole or blowing cave, quite independent of whether there is or is not any ice.

Another scarcely noticed point about natural refrigerators is their relation to life. Apropos of this is the following statement about the talus at Ausable Pond. This is directly on the shores of the lake, and it is known among the Adirondack guides that in front of the talus is the best spot in the whole lake to catch trout. Of course this is because the water of the lake is coldest at that spot, and trout always seek the coldest water. In the literature about glacières, however, I have found reference to an insect, *stenophylax hieroglyphicus*.† This has been found in three caves situated a long distance apart in the French Alps. Although this single case can scarcely be considered as establishing a special glacière fauna, yet the subject is worth further investigation.

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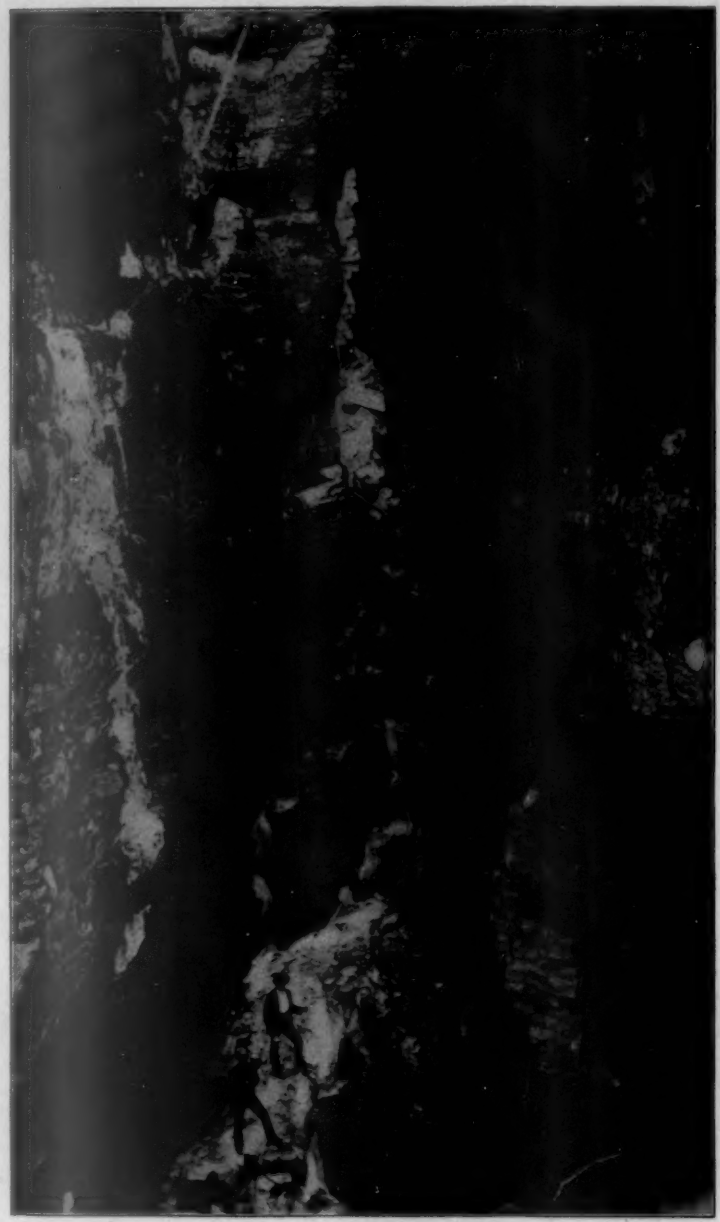
* Further observation on this point will be necessary. The cave at Farrandsville and the talus at Spruce Creek seem to me to offer unusually good opportunities for study.

† G. F. Browne, *Ice Caves in France and Switzerland*, London, Longmans, 1865; and the same in *Good Words*, Edinburgh, November, 1866.



GORGE AT ELLENVILLE, N. Y. (Photo. by Mr. Davis.)

There is more to be said in regard to plant life than to animal life. My guide to the Randolph Ice Gulch told me that he had been assured that Alpine plants similar to those found on Mounts Washington and Adams were found in the Gulch, but that they were not found on the neighboring Crescent and Bald Mountains. On the talus at Spruce Creek, it seemed to me that the flora was somewhat different from that immediately surrounding it. While at the talus at Ausable Pond, Mr. Howell called my attention to the flowers of the bunchberry and also to *oxalis*, a pretty white flower. These were in full bloom, although they were at least two weeks later than they were on the surrounding mountains. Here, therefore, is a case where the cold air coming from the rock crevices affects the flora in the vicinity sufficiently to retard its development.

THE PROBLEM OF THE MISSISSIPPI.

By Herman Haupt, C. E., Washington, D. C.

In May, 1897, the writer published several articles in the *New York Sun* on the Mississippi River problem, the aim of which was to show that of the systems proposed, neither the levee, the outlet, the reservoir, nor any other, singly, would secure protection from overflow, but that a combination of several and an intelligent application of certain recognized principles, with a careful study of local conditions was essential to a practical solution of the problem presented.

Since that time an exceedingly valuable paper has been given to the public by Mr. William Starling, Chief Engineer of the Lower Yazoo District in Mississippi, giving details not in possession of the writer at the time of the publication of the article referred to.

There has been much controversy as to the effect of levees in causing elevation of the beds of streams and very positive assertions have been made on both sides.

The statement was made by Prony that "the Po and the

Adige and almost all of their tributaries are now confined between high artificial banks and although a much larger portion of foreign matter is carried to the sea, yet a part of the sand and mud which formerly was deposited on the plains, now subsides in the bottom of the river channel and it becomes necessary, in order to prevent inundation in the following spring, to extract matter from the bed and add it to the banks. It is sometimes necessary to give an additional height of 1 foot to the banks of the Adige and Po in a single season."

In his "Principles of Geology" (Eleventh Edition, Vol. I, page 420), Lyell also states that the level of the Po has been raised by deposits.

Geike, in "Text Book on Geology," page 394, states that "between Mantua and Modena the Po is said to have raised its bed more than 5½ meters (18 feet) since the fifteenth century." Mantua and Modena are on tributaries on opposite sides of the Po, but the bottom of these tributaries could not have been raised without raising the Po also.

Mr. George P. Marsh, in a work published in 1877, says that the bed of the Po has been somewhat elevated by the deposits in the channel, though not so much as has been often represented.

Lombardini is quoted as asserting that the rate of elevation of the bed of the Po has been much exaggerated by early writers and the same is true of the bed of the Rhone and other important rivers while, on the other hand, the beds of the Adige and the Brenta are raised considerably above the level of the adjacent fields.

It appears to be very clear from these quotations that no proper conclusion can be reached in regard to the effect of levees in raising the beds of streams without taking into consideration the local conditions.

To understand this subject, it is necessary to refer to fundamental principles.

The transporting power of water depends upon its velocity. When the sectional area of a stream is contracted, the velocity, to discharge a given volume of water in a given time, must be increased, and when the area is enlarged, it will be diminished.

In a silt-bearing stream any diminution of velocity must cause deposits, and any increase of velocity from contraction of sectional area, or increase of slope, must suspend deposits entirely and sometimes produce a scour. It is possible, therefore, that one writer may assert that the bed of a certain stream may have been raised by deposits, and another deny the fact, and both may be correct in consequence of observations made at different localities.

In the case of the Mississippi River, it is well-known that an immense quantity of sediment is, in times of flood, carried by the stream. The whole area of country from Cairo to the Gulf of Mexico, a distance of 1,100 miles, constitutes a vast alluvial deposit, which is still rapidly extending by encroachment upon the Gulf.

By these deposits not only has the bed of the stream at Cairo been raised more than 300 feet, but also all the adjacent country, to the extent of many thousand square miles.

When the stream overflows its banks, the heavier particles are first deposited and the lighter carried to a greater distance, in consequence of which there are ridges of coarse material on each side of the stream 12 to 15 feet higher than the country farther back, which slopes gradually to the distant foot-hills.

Continuous levees on both sides would prevent these overflows and would confine deposits when made to the bed of the river or to the delta at its mouth.

If the river were straight, or nearly so, the levees parallel and the slopes uniform so as to maintain a constant velocity in the stream from Cairo to the Gulf, there would be no deposits in the bed, except where the velocity became reduced below that of the tributaries on the upper portion of the main river. All the sediment would then be carried to the Gulf, and would form deposits with unprecedented rapidity, but these conditions do not exist. The fall of the stream is said to be 5 inches per mile from Cairo to Memphis; 4 inches from Memphis to Vicksburg; 3½ inches from Vicksburg to Red River; 2 inches from the mouth of Red River to New Orleans; and 1 inch from New Orleans to the Gulf.

These variations of slope would necessarily produce variations of velocity, and unless the sediment had been previously deposited every reduction in velocity would cause new deposits in the bed, and every increase in velocity from contraction of the cross section by levees or otherwise would suspend such deposits, or, in some cases, might even depress the bottom by producing a scour.

As there are variations of slope and constant contraction and expansion of sectional area, there must necessarily be frequent changes of velocity, and, as a matter of course, there will be deposits in some portions of the bed and none in others, with occasional scour tending to the formation of holes.

This opinion derives confirmation from a valuable paper by Prof. J. B. Johnson, read before the American Association for the Advancement of Science, in 1884, in which this language is used:

"It would seem, therefore, that in the river's present condition, there is no evidence that a confined flood will scour out its bed so as to facilitate the discharge, and there is considerable evidence against it. If the river flowed between straight parallel banks, such as Captain Eads has constructed at the mouth of the river, there then could be no such thing as discontinuous transportation of sediment, and hence no alternate scour and fill. Then concentration of volume would be beneficial and would ultimately lower the river bed. But this condition of things can never be reached on the Mississippi River, and hence the concentration of flood volume will be harmful rather than beneficial."

EFFECT OF CONTINUOUS LEVEES.

To form an opinion as to the increased height of floods that will result from the construction of strong continuous levees, it is necessary to know, at least approximately, the additional volume of water that in extreme floods may be thrown into the main river.

It is stated by William Starling that if all the tributaries of the Mississippi were in flood at the same time the discharge would reach 3,000,000 cubic feet per second.

The flood of 1897 proceeded mostly from the Ohio, and the discharge at Cairo was 1,570,000 cubic feet per second, and below the mouth of the Arkansas, 1,740,000 cubic feet per second.

Others have estimated maximum floods at 2,000,000 cubic feet per second, of which only 1,000,000 cubic feet reached the mouth of the river; the remainder covered and formed deposits in the swamps and found its way by outlets and cut-offs to the Gulf.

Below Cairo and above Helena and Vicksburg there are the two great basins of the St. Francis and the Yazoo.

The basin of the St. Francis contains 6,706 square miles and the basin of the Yazoo 6,648 square miles.

There are also several other extensive basins which are important factors in any attempt to solve the problem of the Mississippi. These are:

The White River Basin, embracing 956 square miles.

The Tensas Basin, 5,370 square miles.

The Atchafalaya Basin, 8,109 square miles.

The Pontchartrain Basin, 2,001 square miles.

The aggregate of these basins is 29,790 square miles.

Each basin is bounded by a ridge and drained by a river, which usually flows near the base of the ridge.

The great alluvial bottom of the St. Francis is 190 miles long and 35 miles wide, bounded by Crowley's Ridge, which abuts upon the river at Helena. This ridge has no gaps, and is said to be far above the highest water of the Mississippi.

The elevation and width of this ridge might possibly render it impossible, at any reasonable cost, to provide a cut-off to discharge a portion of the surplus water in high floods into the lower valleys and prevent their return to the main river. If this be the case, the overflow into the St. Francis basin must be discharged into the river at Helena, and add to the height of the flood, but the reservoir still will have a very beneficial effect in delaying the arrival of the crest of the wave at Helena from six to eighteen days. The outpour from the St. Francis produces a rise at Helena of 1 foot per day for three or four days. If the St. Fran-

cis and Yazoo basins were closed entirely by levees, the height of the flood would be greatly increased. Starling remarks: "The closure of the upper basins will have the undesirable effect of bringing the floods from the upper river into closer coincidence with those from the White and Arkansas, and this may justly be considered a serious element of danger."

Starling estimates that the closure of the St. Francis and White River basins will raise the crest of the flood at Helena 5 feet.

"The St. Francis was closed since 1893 to a distance measured along the river of 120 miles and a gap of 100 miles still remains. It is to the building of these levees and to the maintenance of the lines previously existing that the unparalleled stages attained by the water has been due."

It is also stated by the same writer that the gauge at Sunflower would undoubtedly have stood 7 feet or more above all previous records if crevasses had not occurred in the levees in front of the White River basin and the levees would have been deeply submerged if something had not given way.

If the partial closing of the levees in front of some of the basins has resulted in such an enormous increase of flood height that the most elevated levees would have been overtopped and submerged but for the relief afforded by crevasses, what result may be expected when the whole river is confined by continuous levees on both sides? If the volume of water that is poured into the upper portion of the Mississippi is twice as great as is now discharged at its mouth, what must be the elevation of the crest lines of the flood when the volume is doubled? The idea that an increase of velocity will result from the increased volume and, that in consequence, a scour will be produced that will increase depth sufficiently to compensate for increased height of flood has been shown to be fallacious. If there was a continuous scour the material must be deposited somewhere, and the only conceivable place of deposit would then be at the Gulf, reinforced by all the material brought in from the tributaries and from erosion

of the banks, in which case the amount would be so enormous that it would be almost impossible to maintain navigation and New Orleans might become an inland city. Heretofore, relief has been afforded by crevasses and cut-offs by which it is said that half the volume in flood stages has found its way to the Gulf through swamps, bayoux and secondary streams, and was not discharged through the passes. When these avenues of escape are cut off there must necessarily be a great increase in the flood height unless some other mode of relief can be provided.

CAN RELIEF BE AFFORDED BY RESERVOIRS?

At the St. Francis basin in the natural condition of the river the water begins to escape from the Mississippi and run over its banks at a stage of about 39 feet on the Cairo gauge or 40 feet at Helena, and the volume diverted is 300,000 cubic feet per second or more. This overflow consumed seventeen days in 1890 and twenty-three days in 1891 in reaching Helena. The extreme high water in Cairo has been 51·83 feet. The highest point reached at Helena since 1870 was almost exactly the same or 51·85 feet. The ordinary level at Cairo has been given at 294·71 above mean tide, and at Helena 165·00. The difference is 129·71 feet and if the direct distance be taken at 190 miles the general slope of the basin would be 8 inches per mile.

To convert the basin of the St. Francis into a great reservoir or lake of 6,706 square miles capacity with slack water throughout its whole extent, the level of the surface must be 346·54 feet above tide, and the height of a dam and levees at Helena would be required to be 182 feet. If it be assumed that the surface of this reservoir in consequence of a discharge at its lower end should have the same fall as that of the river or 5 inches to the mile, the height of the structure at Helena to retain it must be over 100 feet.

To convert the basin into a reservoir to hold back the floods would destroy the agricultural lands, which are said to be valuable.

If the basin of the St. Francis should be leveed throughout its whole extent and the mouth of the river alone left

open, the backwater would extend from low-water line 78 miles, and to protect the arable lands in this portion of the basin the banks of the St. Francis must also be leveed.

The idea of converting the basins of the Mississippi into reservoirs to hold back the floods must be abandoned as impracticable, as similar difficulties would be presented in the other localities.

THE OUTLET SYSTEM.

The advocates of the outlet system claim the ability to reduce the height of the floods and prevent overflow by providing outlets to secure a more rapid discharge of the water in time of flood by a more direct channel to the Gulf.

It is stated that a crevasse at Bonnet Carre, a short distance above New Orleans, which discharged one-twelfth of the flood water through Lake Pontchartrain, in going 6 miles instead of 160 miles to the river's mouth, lowered the high-water mark at New Orleans from 3 to 4 feet, where the rise and fall was 17 feet, and lowered it at Natchez, 300 miles above, from 6 to 8 feet, where the rise and fall was 50 feet.

It is also claimed that an outlet 1 mile wide by 10 to 12 feet deep, with a fall of 12 feet in going 6 miles to Lake Borgne, would divert one-twelfth more of the discharge and reduce the high-water level at New Orleans in all 8 or 10 feet, and at Natchez, from 14 to 15. Whether these published statements be accepted as reliable or not there can be no question that outlets will reduce the height of floods if properly located and of sufficient number and size. In fact, nature provides them for its own relief, by means of the crevasses, which afford protection to localities many miles distant. It would seem, therefore, that permanent outlets properly located might afford permanent relief. Objection is made that the change in the velocity of the current below the crevasses causes the formation of bars and results in an impediment to low-water navigation.

The most serious objection to the outlet system is that while it might afford relief in high water, it would cause

evils in low stages by diverting water required for navigation.

It would not be difficult by means of an outlet of sufficient size to turn the bulk of the waters of the Mississippi into the Atchafalaya, which would give a shorter distance to the Gulf, a steeper slope, and a more rapid discharge.

What is needed is to maintain in the Mississippi the depth for navigation, and discharge the excess as rapidly as possible, which requires that the plan adopted should not permit a discharge at too low a level.

CONTRACTION.

Contraction is a local remedy to produce a scour for the removal of bars and deepening of navigation. It consists in reducing the cross-section and thereby increasing the velocity at certain points. In some cases it may be expedient to resort to dredging to secure a channel that can afterward be readily maintained in low water by a contraction of the cross-section. It is in general easier to maintain a channel than to create it by means of scour. Contraction is one of the auxiliary means to which the engineers must resort in special cases. It is not applicable to continuous improvement.

REVETMENTS

A river flowing through an alluvial plain has a constant tendency to change its course and produce a series of horseshoe curves. The constant erosion gradually reduces the distance across at the heel of the shoe, and at length a high flood breaks over and cuts away the intervening neck of land and creates a new channel, leaving in place of the old channel a bayou often many miles in extent.

This action often menaces important cities such as Vicksburg and Memphis, and renders necessary protection against the eroding action of the stream.

It is also an object of great importance in the interest of navigation that the bank of the stream should be protected from this erosive action, since the vast amount of material removed must be redeposited at other points in the bed of the stream, forming serious obstruction to navigation.

The protection of the banks by revetments is therefore an object of importance, and the benefit to be derived therefrom is not merely local, but general. It concerns, however, the question of navigation rather than the protection of plantations from overflow.

A POSSIBLE SOLUTION OF THE PROBLEM.

The objects sought are twofold—to maintain a navigable channel in the Mississippi in low water, and to prevent the destruction of life and property by floods.

The evidence presented should be conclusive that parallel levees of any ordinary height, continuous on both sides of the streams, with outlets all closed, compelling the river to carry and discharge into the Gulf double the former volume of flood water will not, with certainty, secure the country permanently against overflow, but when the limit of the capacity for protection has been attained the danger from crevasses, if they should occur, will be vastly increased.

It may be that careful unbiased examination will lead to the conviction that the continuous levee system, bad as it is, is, nevertheless, the only one practicable, and that whatever may be the height to which levees must be raised, the expense must be incurred to avoid evils of greater magnitude, but this conclusion should not be reached without the most thorough investigation.

THE WASTE WIER SYSTEM.

There is one system which holds out a promise of more satisfactory results than any other, and which has not, so far as known to the writer, formed the subject of any extended discussion, and that is a system of *waste wiers*, to discharge the excess above a safe level in extreme floods without reducing the volume required for the navigable stages.

Every canal engineer understands that in constructing a summit level to supply lockage for his canal, he must provide what are called waste wiers, so that when floods fill the feeders and the canal level to a certain height, the surplus will be discharged over wiers into the natural water chan-

nels of the country, and thus prevent a rise that would endanger the banks.

By a similar arrangement, if local conditions would permit, extensive wiers might be provided at suitable points along the Mississippi which would be inoperative under ordinary conditions of the stream, but when the river reached a level, to be determined by the engineer in charge, the surplus would begin to pour over the wiers and discharge into the Gulf by the Atchafalaya and other streams.

The effect would be not only to reduce the height of the flood, but also to carry off a large amount of the sediment that would otherwise be deposited in the bed of the river or carried through the passes to form bars in the channel at its mouth, and it would also help to fill up the swamps, and thus, in time, add to the area of arable land.

As to the proper location for such wiers no decision can be reached without a careful and intelligent study of localities with special reference to the settlement of the question with all the collateral questions which it involves, but an examination of the carefully prepared maps of the U. S. Engineer Department would seem to indicate that if the elevation of Crowley's Ridge near Helena is not excessive, a cut of moderate length would throw a portion of the high water volume of the St. Francis into the headwaters of the White River, while another cut of greater length, but over ground of low elevation, would turn a large volume into the tributaries of the Atchafalaya and lead by a short cut to the Gulf. These cut-offs would be entirely dry except when the floods had reached a dangerous elevation.

The waste wiers on the west side of the river would also, by lowering the surface level of the river, afford relief on the east side, but so far as concerns the basins of the Yazoo and Big Black, no relief by a cut-off to the Pearl would appear to be practicable, as the country between these rivers is too high. It would appear to be practicable, however, to divert a portion of the high-water discharge of the Arkansas and the Red into the Atchafalaya, and thus greatly relieve the levees of the lower river.

These suggestions are made with much diffidence, as it

will require a thorough examination of localities to decide the question of practicability.

QUANTITY OF DEPOSITS.

With continuous levees on both sides of the Mississippi, from Cairo to the Gulf, thus preventing any lateral deposits, the quantity of solid material carried by the stream must be enormously increased, particularly when reinforced by the erosion from the banks.

All the material must be carried to the mouth, with the exception of the portion deposited upon the bed.

It has been estimated, as previously stated, that with the tributaries in full flood at the same time as the main river, the total discharge might reach 3,000,000 cubic feet per second, but an estimate will be made on 2,000,000 as conservative during a high flood.

In 1879 Colonel Suter found the mean proportion of water to sediment at St. Charles, near the mouth of the Missouri, to be 265 to 1, but below Cairo, after dilution with the clearer water of the Ohio, the proportion was only 1,061 to 1.

On the basis of this proportion and allowing no addition for erosion of river banks, the deposit at the mouth of the Mississippi would cover, in twenty-four hours, an area of 4,050 acres, or 6⅓ square miles, to a depth of 1 foot. It is also stated that since 1838 the fill 10 miles out from the passes has been 620 feet, which at the same rate continued would carry it to the surface in eighteen years. The completion of the continuous levee system would enormously increase the volume of these deposits and necessitate great rapid and continuous extension of the jetties with constant dredging. This is an important factor to be considered in the determination of any plans for improvement.

THE FIRE UNDERWRITERS' RULES FOR SAFE INTRODUCTION OF ACETYLENE GAS GENERATORS.

Communicated, with some introductory remarks, by CHAS A. HEXAMER, Member of the Institute.

The rapid increase in the use of Acetylene Gas as an illuminant, demonstrated to Underwriters' Associations throughout the country the necessity of rules for safe introduction of acetylene gas generating apparatus. Various associations have attempted to control such installations by adopting forms of permits and rules. These rules indicate considerable difference of opinion in regard to the fundamental question whether or not the generating apparatus, when gas is generated directly from calcium carbide, could safely be allowed in the insured building, and whether or not liquefied acetylene gas, or gas generated from same, could be used with safety under any circumstances.

In order that the question relating to the placing of the generating apparatus in an insured building could be decided, and for the purpose of preparing uniform rules for use throughout the country, the Committee on Heating, Lighting and Patents of the National Board of Fire Underwriters, issued a call for a meeting of duly authorized representatives of Underwriters' Associations, for the purpose of a conference, and, possibly, agreement on general rules for the safe use of the new illuminant. This meeting was held in New York in June, 1898, and was well attended. The question of the location of the generating apparatus in the insured building was first considered, and led to so protracted a discussion that it became apparent that it would be necessary to refer the question of general rules to a special committee. The conference having adopted a resolution providing for the location of the generating apparatus inside a building, subject to discretion of Underwriters' Associations having jurisdiction, a special committee was appointed,

which, in December, 1898, unanimously reported the rules printed below.

After a careful consideration and approval of the rules by Prof. Henry Morton, of Stevens Institute, Hoboken, N. J., they were submitted by the National Board of Fire Underwriters to the various Underwriters' Associations for adoption.

In formulating the rules, it was the aim of the Committee to treat the subject as broadly as possible, and without specifically describing a standard generator to lay down fundamental principles and rules beyond which it is unsafe to go.

NATIONAL BOARD OF FIRE UNDERWRITERS.

COMMITTEE ON LIGHTING, HEATING AND PATENTS.

156 Broadway, N. Y.

ACETYLENE GAS RULES.

NEW YORK, December 27, 1898.

At the last annual meeting of the Board, the Committee on Lighting and Heating submitted proposed regulations for the installation of acetylene gas apparatus which were referred back to the Committee with instructions to call a meeting of the experts of the several Underwriting Associations in order to secure uniform rules on the subject throughout the country. That meeting was held on the 21st and 22d of June, 1898, when a careful consideration of the points at difference between the Associations led to a reference of the matter to a special committee composed of Messrs. Charles A. Hexamer, of the Middle Department Association, Philadelphia; W. A. McCutcheon, Inspector Board of Underwriters, Pittsburgh; W. C. Robinson, of "The Union," Chicago; F. M. Griswold, New York; W. B. Medlicott and Ellwood Hendrick, of the New England Exchange, Boston. That Committee held several meetings, giving the most thoughtful care and attention to the subject, and finally reported the following rules, which, having also received the approval of our scientific expert, have been duly adopted by this Committee, and are now promulgated as the Standard of the National Board of Fire Underwriters.

The Committee regrets the delay in the issue of the rules, which, however, was unavoidable, because of the differences of opinion which existed on important points, and which it was desirable to harmonize in the interest of all. It is recommended that all Associations and Boards of Fire Underwriters adopt the rules, of which action please send notice to H. K. Miller, Secretary, 156 Broadway, New York, of whom additional copies of the rules can be had.

HENRY H. HALL, Chairman, New York.
J. H. WASHBURN, New York.
JAMES NICHOLS, Hartford.
R. DALE BENSON, Philadelphia.
H. F. ATWOOD, Rochester.

NATIONAL BOARD RULES GOVERNING CONSTRUCTION OF STANDARD APPARATUS.

The use of liquid Acetylene or gas generated therefrom is absolutely prohibited.

The permission to generate and use Acetylene in insured premises shall be subject to the following rules.

APPARATUS.

It is desirable that all Acetylene Gas machines shall be installed outside of the building insured, but special permission may be granted in the discretion of tariff associations having jurisdiction to install machines inside the building under special circumstances, such permission to be given in writing and shall be subject to the following rules:

(1) Must be made of iron or steel, and in a manner and of material to insure stability and durability.

(2) Must have sufficient carbide capacity to supply the full number of burners during the maximum lighting period.

NOTE.—This rule removes the necessity of recharging at improper hours. Burners almost invariably consume more gas than their rated capacity and carbide is not of staple purity, therefore, there should be an assurance of a sufficient quantity to last as long as light is needed. Another important feature is that in some establishments burners are called upon for a much longer period of lighting than in others, which requires a generator of greater gas-producing capacity.

(3) Must be uniform and automatically regulated in its action, producing gas only as immediate consumption demands, and so designed that gas is generated without excessive heating at all stages of the process.

NOTE.—This rule is necessary, because the presence of excessive heat tends to change the chemical character of the gas and may even cause its ignition.

(4) Apparatus not requiring pressure regulators must be so arranged that the gas pressure cannot exceed thirty tenths inches water column (three inches).

(5) Must be provided with an escape pipe which will operate in case of the over-production of gas, and also an attachment acting as an escape or relief in case of abnormal pressure in the machine, and which will carry such excess gas through an escape pipe of at least three-quarter-inch internal diameter to a suitable point outside of building, discharging at least twelve feet above ground level and provided with an approved hood.

NOTE.—Both the above safety vents may be connected with the same escape pipe.

(6) Apparatus requiring pressure regulator must be so arranged that the gas pressure cannot exceed three pounds to the square inch. Such apparatus must be provided with additional safety blow-off attachment located between the pressure regulator and the service pipes and discharging to the outer air, the same as provided for in Rule 5.

NOTE.—This is intended to prevent the possibility of undue pressure of gas in the service pipe by failure of the pressure regulator.

(7) Must be so arranged that when being charged the back flow of gas from the holder will be automatically prevented, or so arranged that it is impossible to charge the apparatus without first closing the supply pipe to holder, or to other generating chambers, if any.

NOTE.—This is intended to prevent the dangerous escape of gas.

(8) Must be so arranged as to contain the minimum amount of air when first started or recharged, and no device or attachment facilitating or permitting mixture of air with the gas, prior to consumption, except at the burners, shall be allowed.

NOTE.—Owing to the explosive properties of acetylene mixed with air, machines should be so designed that such mixtures are impossible.

(9) No valves or pet-cocks opening into the room from gas-holding part or parts, the draining of which will allow an escape of gas, shall be permitted; and the condensation from all parts of the apparatus must be automatically removed without the use of valves or mechanical working parts.

NOTE.—Such valves and pet-cocks are not essential; their presence increases the possibility of leakage. The automatic removal of condensation from the apparatus is essential to the safe working of the machine.

(10) The water supply to generator must be so arranged that gas will be generated long enough in advance of the exhaustion of the supply already in the gas holder to allow of the using of all lights without exhausting such supply.

NOTE.—This provides for the continuous working of the apparatus under all conditions of water feed and carbide charge, and it obviates the extinction of lights through intermittent action of the machine.

(11) No carbide chamber of over twenty-five pounds capacity shall be allowed in any machine where water is introduced in small quantities or where the contact of water with carbide is intermittent.

NOTE.—This tends to reduce the danger of overheating, and provides for the division of the carbide charges in machines of these types of large capacity.

(12) Generator must be connected with the gas-holder in such manner that it will, at all times, give open connection either to the gas-holder or to the blow-off pipe into the outer air.

NOTE.—This prevents dangerous pressure within or the escape of gas from generating chamber.

(13) Must be so designed that the residuum will not clog or affect the working of the machine and can conveniently be handled and removed.

(14) Covers to generators must be provided with secure fastenings to hold them properly in place, and those relying on a water seal must be submerged in at least twelve inches of water. Water seal chambers for covers depending on a water seal must be one and one-half inches wide and fifteen inches deep, excepting those depending upon the filling of the seal chambers for the generation of gas, where nine inches will be sufficient.

(15) Holder must be of sufficient capacity to contain all gas generated after all lights have been extinguished.

NOTE.—If the holder is too small and blows off frequently after lights are extinguished there is a waste of gas. This may suggest improper working of the apparatus and encourage tampering.

(16) The bell portion must be provided with a substantial guide to its upward movement, center guide preferred, and a stop acting about one inch above the blow-off point.

NOTE.—This tends to insure the proper action of the bell and decreases the liability of escaping gas.

(17) A space of at least three-quarters of an inch must be allowed between the sides of the tank and the bell.

(18) All water seals must be so arranged that the water level may be readily seen and maintained.

(19) Gas-holders constructed upon the gasometer principle must be so arranged that when the gas bell is filled to its maximum its lip or lower edge shall at all times be submerged in at least nine inches of water.

(20) The supply of water to the generator for generating purposes shall not be taken from the water seal of any gas-holder constructed on the gasometer principle.

NOTE.—This provides for the retention of the proper level of water in the generator.

(21) The apparatus shall be capable of withstanding fire from outside causes without falling apart or allowing the escape of gas in volume.

NOTE.—This prevents the use of joints in the apparatus relying entirely upon solder.

(22) Gage glasses, the breakage of which would allow escape of gas, shall not be permitted.

(23) Where purifiers are installed, they must conform to the general rules for the construction of other apparatus and allow the free passage of gas.

(24) The use of mercury seals is prohibited.

NOTE.—Mercury has been found unreliable as a seal in acetylene apparatus.

(25) Construction must be such that liquid seals shall not become thickened by the deposit of lime or other foreign matter.

(26) Apparatus must be constructed so that accidental syphoning of the water is impossible.

(27) Flexible tubing, swing joints, packed unions, springs, chains, pulleys, stuffing boxes and lead or fusible piping must not be used on apparatus, except where the failure of the part will not vitally affect the working or the safety of the machine.

(28) There shall be plainly marked on each machine the maximum number of lights it is designed to supply and the amount of carbide necessary for a single charge.

To be approved, Acetylene Generators must conform to the foregoing standard, and plans and specifications in detail of such apparatus must be submitted to the insurance organization having jurisdiction over the territory in which such apparatus is to be installed, for approval by an inspector duly authorized by the . . . . . Association, with whom a copy of such plans and specifications must be filed. If the plans are approved, a special examination of the Generating Apparatus will be made at the expense of the applicant, and if it is found to be in compliance with the standard, a certificate of approval will be issued.

CALCIUM CARBIDE.

(1) In no case shall Calcium Carbide be stored in bulk.

(2) Calcium Carbide must be packed in screwed-top, water-tight metal packages, having all seams lock-jointed and soldered. They shall contain not over 125 pounds of Carbide, and each package must be conspicuously marked "Calcium Carbide, Keep Dry." The packages must be of sufficient strength to insure the handling of the same without rupture, and they must be kept under cover at all times.

INDORSEMENT FOR USE OF ACETYLENE GAS.

In consideration of the following warranties on the part of the assured, permission is hereby granted to generate and use Acetylene Gas on the premises described in this policy, using a . . . . . Acetylene Gas Machine, manufactured by . . . . . at . . . . . when the same is installed in accordance with the rules and regulations of the National Board of Fire Underwriters, and adopted and promulgated by the . . . . . Association.

WARRANTED.

That the Generator shall be charged, and Calcium Carbide handled by daylight only;

That no direct fireheat or artificial light shall be allowed in the room containing the apparatus;

That no Calcium Carbide shall be kept in the building where this policy covers;

That no greater number of lights shall be installed than the maximum for which the machine is rated;

That no change shall be made in the installation without the written consent of this company indorsed hereon.

Attached to and made a part of Policy No. . . . . of the . . . . . Insurance Company, of . . . . . .

The use of Liquid Acetylene, or Gas generated therefrom, on the premises described herein is absolutely prohibited.

CAUTIONS.

Calcium Carbide should be kept in water-tight metal cans, by itself, outside of any insured building, under lock and key, and where it is *not* exposed to the weather.

A regular time should be set aside for attending to and charging the apparatus during *daylight* hours only.

In charging generating chambers, clean all residuum carefully from the containers and remove it at once from the building. Separate the unexhausted Carbide, if any, from the mass and return it to the container, adding new Carbide as required. Be careful never to fill container *over* half full, as it is important to allow for the swelling of Carbide when it comes in contact with the water.

Never place Carbide into the containers until all residuum has been carefully removed.

Water tanks and water seals must always be kept filled with clean water.

Where apparatus is not intended for use throughout the year, all water must be removed at the end of season.

Never use a lighted match, lamp, candle or any open light near the machine.

ELECTRICAL SECTION.

"Railroad" Meeting, March 28, 1899.

SOME OF THE LARGER TRANSPORTATION PROBLEMS IN CITIES.

BY EDWARD E. HIGGINS.

The managers of a large city railway system are constantly called upon to deal with problems of great difficulty and complexity. They have a double responsibility—a responsibility to the public and a responsibility to the investors of whose interests they are trustees. They are charged with the management of thousands of employés, whose attitude toward the enterprise, whether of content or discontent, is of vital importance to its success. They must pass upon inventions and improvements in the science of municipal transportation, determining where cost and true economy join hands; they must adopt operating methods adequate to the development of the system and of the city which it serves; they must care for the comfort and pleasure of the public; and they must so unify all of these varied and sometimes conflicting duties as to develop an organization and management successful as a whole and not unduly weak in any part.

Grave misunderstandings often arise between street railway companies and the public. The people often believe the companies to be grasping, sordid, careless of their duties as public carriers and desirous only of making the largest possible return to stockholders. The companies, on the other hand, daily harassed by complaints about inconveniences suffered, small or large, often came to regard the public as unreasonable in its demands, forgetting that that public is not in a position to see all the difficulties and perplexities which beset the management at every turn, and which make it often either impossible to grant such demands or to explain why they cannot be granted. The

street railway business, as a whole, is so complicated and so much a matter of detail, that no one department of it can be well understood without some knowledge of the others, and fragmentary or partial explanations of the reasons for specific decisions, however sound in their relationship to the general plan of management, might not always or often appear so to non-technical critics.

I shall attempt in the following discussion to give such an explanation of the entire scheme of modern street railroading on its broad lines and of the principal problems which the manager has to solve, as will lead to a clearer understanding, by those who are not of "the faith," of what the public has a right to expect from the street railway companies, which are its servants and which are, as a rule, honestly trying to fulfil all the obligations which can reasonably be imposed upon them.

ESSENTIAL DIFFERENCES BETWEEN CITIES.

In the first place it cannot be too clearly made evident how different are the transportation conditions in each city from those of any or all other cities. Nothing can be more fallacious, or lead to greater injustice, than to say that because such and such concessions are granted by the companies to the people of a certain city, therefore, similar ones can and should be made in another city. The most common error of all perhaps is to assume that the conditions found in a small city obtain in a large one or *vice versa*. Population and population density have an enormous influence on street railway earnings, profits and possibilities of generosity. A second even more common error is to hold that as much ought to be expected from an old company which has passed through one or more experimental stages of street railroading and had to throw away enormous investments for antiquated motive powers and to purchase their substitutes at high initial prices, as from a new company just entering the field, with all the accumulated experience of many years to draw upon, and with the benefit of low prices for material and supplies of the present day. Behind these more obvious injustices come others less easy to understand without

some technical exposition. How, for example, can a manager satisfactorily explain to the public the reason why the people of his city patronize their street railway system to the extent of only $3 per capita per annum, while in another city of the same population, the earnings are over $5 per capita? When the generosity of the richer system is cited as a precedent for the poorer to follow, it is a delicate matter to show that the latter's public is largely composed of the working classes to whom the daily 5- or 10-cent fare forms a material burden, or a difficult one to make clear that the plans on which the two cities are laid out are radically different, the one calling for greater patronage of street car lines than the other, without necessarily involving greater expense to the operating company. A knowledge of these differences in city plans and lines of development is so essential to the understanding of the theory of street railroading that a brief explanation of their effect upon earnings is desirable.

The world's great cities are, with scarcely an exception, built upon or around some form of water front—sea, lake or river. Upon some section of this water front is always found the "congested district," devoted to commercial and business purposes. The manufacturing districts of a city may or may not be on this water front, according to the location of the railroad termini and branches, the presence or absence of rivers tributary to the main water front, and other governing conditions. All, or nearly all cities are laid out and developed on one of four distinctive plans, (1) the peninsula plan, such as that of New York City (Manhattan Borough) and San Francisco; (2) the valley plan, with a river or rivers running through the center, such as Pittsburgh; (3) the radiating plan, with territory on one side only of water front, such as Chicago, Boston, Brooklyn and many other cities; and (4) the radiating plan, with territory on both sides of the water front, of which examples are found in Metropolitan New York (including Eastern New Jersey), Paris, London and many other cities, large and small.

The peninsula and valley plans usually call for compara-

tively small street railway track mileage, and great traffic density is found on that mileage, together with large gross earnings per capita served, per mile of track and per car mile. For example, the complete transportation system of New York City proper (Boroughs of Manhattan and the Bronx) earns about $13 per capita gross, and that of San Francisco nearly $14. The radiating plans mean greater street railway mileage for the population served, and usually a much less density of traffic and less gross receipts per capita. The Chicago surface and elevated lines, for example, earn less than $10 per capita, and the surface lines of St. Louis hardly $8 per capita.

It can be easily seen how different, for example, is the transfer problem in a peninsula and valley city from that of a radiating city. In the former there may be a few through lines of heavy traffic, with many cross-town feeder lines. Transfers in such a city might mean no additional expense to a company and little or no complication. In the radiating city, on the contrary, a transfer system might mean a ride of great length, while the plan of the system might be such that dishonesty in the use of transfers would be easily possible.

Again, a city plan very favorable to economical operation might make a 4-cent fare possible in a given city, while in another city, even of the same population, such a fare would mean bankruptcy. A city system of large track mileage running many cars might have immense maintenance accounts to deduct from earnings, whereas, a more fortunate one in another city would have a great traffic density on small mileage. All that a comparison of practice between the street railway systems of two cities can do, therefore, is to put the burden of proof upon the system which is apparently less generous with the public of showing why the more generous practice cannot be followed, and the company's argument should be received with attention and respect, for after all, nothing is more certain than that the best reasonable service of the public will bring about the largest earning power to a street railway company, and none is more quick to recognize this fact than the average street railway manager.

THE FUNCTION OF ELEVATED AND UNDERGROUND RAILWAYS IN CITY TRANSPORTATION SYSTEMS.

The question of adding to existing facilities or solving different congested district problems by the building of elevated or underground railways is facing the managers of several of the principal cities of the world, and it is a serious one indeed. The enormous cost of tunneling, and the hardly smaller combined investment required for building an elevated structure, and paying damage claims to abutting property owners, leads and will lead to a postponement of the issue as long as possible. The great tunnels of Paris are an immense burden upon French taxpayers, while private capital cannot hope to make a success of tunnel enterprises except in countries where rates of interest are extremely low, and even then the public must usually be called upon to help by special concessions or subsidies of one kind and another. The London Metropolitan underground system is a failure financially, partly because of its immense cost and partly because it was not properly laid out to obtain the greatest density of traffic. It is hoped that the new Central London Underground will be more successful, being comparatively short and built under one of the heaviest traffic routes of that great city. Private capital has so far shown very little enthusiasm for an underground railway in New York City, where, if anywhere in America, such a railroad should prove profitable.

The elevated railway system of Manhattan Island has been in the past exceedingly profitable, chiefly because it is built in a "peninsula city" *par excellence*, where an immense tide of travel sweeps south in the morning and north at night, along few and narrow lines, but the fact that through all these years until the present time the New York elevated lines have had as competitors only comparatively slow-moving horse cars, has been almost equally potent in effecting profits, since short-distance as well as long-distance travelers have been obliged to use the elevated when time is an object. Elevated railroading in the two "radiating cities" of Brooklyn and Chicago has been distinctly unprofitable. In cities of this class it is difficult or impossible to find the

density of traffic necessary for the payment of operating expenses and interest upon the heavy capital outlay required. This is particularly true where the surface cars are run at frequent intervals and at high speeds, for the latter will inevitably obtain the short-distance or more profitable class of traffic, leaving the long-distance or unprofitable class only to the elevated lines. Moreover, in cities of the radiating class, the population is usually spread out over so large an area as to make it impossible for any one line to obtain a large proportion of the traffic. The adoption of electricity on the elevated lines in Chicago has favorably affected gross and net earnings, and with the scaling down of capitalization, which has recently been accomplished, there is a possibility that a reasonable return on the new capitalization can be made if new competitive conditions do not arise; a similar result is hoped for in Brooklyn. It is by no means improbable, however, that the only permanent solution to the problem of running surface, elevated and underground railways in the same city is to have them under one control and management, so that the surface lines can serve as feeders to the elevated or underground lines, an express service only to be given on the latter, and a fare charged for the combined service somewhat greater than the single 5-cent fare.

In the congested districts of our principal cities, elevated or underground lines, either or both, will find a true and valuable field. The business sections of Chicago and Boston furnish problems of the most serious and complicated character, which are only partially solved at present, and are likely to grow graver in geometrical ratio as the years go on, and as the territory tributary to the business centers increases in area and population. It is probable that the only permanent solution to congested district problems in cities lies in subway or tunnel lines and loops in these districts. These will take from the surface of the streets the enormous crowds of people which at morning and evening hours of the day pour into and out of the tall buildings which have become so necessary an evil in the modern city business districts. Boston's new subway is a decided,

though not as yet a complete, success in relieving congestion and saving time throughout a large portion of the twenty-four hours. The new Boston elevated lines at present under construction will be of great assistance in this congested district, passing as they do from its limits on the north and west (the latter projected) to those on the south, and the managers of the great city railway property in Boston have done wisely in confining these elevated lines to the congested district and not carrying them to a greater distance away from the business center. In Chicago, the Loop Terminal of all the elevated lines, recently put into operation, has been a great convenience to the people, and has added largely to the traffic, but it is a question if it has not even so soon reached its train capacity, particularly on days of its heaviest traffic; for on a recent holiday, no less than 65 per cent. of the trackage on one of the loop lines of the structure was covered by trains, *i. e.*, they were less than a train length apart on an average.

THE PROBLEM OF MOTIVE POWER.

No decisions which street railway managers have been called upon to make during the past ten years have caused them such anxious solicitude, and have meant so much to the public and to stockholders as those connected with motive power. Ten years ago horse traction was almost universal, with the cable in use or building on the heavy traffic routes of a few cities, and electricity just coming into sight. To-day electricity reigns triumphant, having displaced both horses and cable on nearly all the mileage of American cities. A synopsis of the reasons for this wonderful revolution in transportation methods which has completely changed the complexion of our cities, and added new life and vigor to their daily routine, will be of present as well as retrospective interest, inasmuch as the primacy of electricity, and particularly of overhead wire electric traction is still occasionally disputed.

All motive powers may be divided into two classes, those which make a car a more or less independent unit on the streets, and those which make it constantly dependent on

some central source of power. To the first class belong the horse car, the storage-battery electric car, the compressed-air car, and various forms of gas, stored steam, petroleum and other motor cars. To the latter belong the cable system and the electric overhead wire and conduit systems.

Independence in the car unit is a highly desirable thing. With it comes minimum disturbance of the pavement or obstruction in the streets with minimum investment for installation; and with it comes also an avoidance of the danger that the central source of power may give out and stop the entire system, or any large section of it for a considerable period. There is no question that a really successful independent unit system would be heartily welcomed by street railway managers, certainly as an auxiliary, and would find a large field immediately ready for occupancy.

But there are serious obstacles to success. It is probably impossible to devise a power generating and using system which will go within the narrow space limits available in a modern popular car, and which shall be capable of exerting as a maximum a power four or five times the average amount required for the propulsion of the car. Such a system can be placed in a dummy car and some room left for passengers as well, but while one or more trail cars are to be drawn, difficulties of traction come up immediately. At all times there is the impossibility of generating power in small amounts with anything like the economy with which it can be generated in large. If power be generated in quantities at some central station and stored in some one of several forms for transfer to, and use on a car, that car, is quite as surely dependent on the central station as it would be were the power transmitted by wires or cable, and is likely to give even more trouble through the exhaustion of the stored power and the consequent stoppage of the car on the line. Still another difficulty is found with so-called independent car operation (except where electric motors are used as in the storage-battery system), and that is the impossibility of producing a rotary motion without the use of an initial reciprocating motion, with all the latter's well-known disadvantages in the matter of wear of

parts and reduction of tractive effort on grades, curves and in starting. Finally, such disagreeable concomitants as odor, noise, or danger of explosion must be excluded if the independent motor is to be an entire success.

Modern street railroading requires constantly increasing average speeds over city streets without increasing danger of accident. With the short runs between streets, and the many stops necessary for taking on and letting off passengers, high average speeds can be obtained only by means of high rates of acceleration in starting, and correspondingly high-braking effort in stopping. In other words, maximum speed must be reached as quickly as possible and kept up as long as possible before brakes are applied.

Now, the one propelling agency adapted for this peculiar class of work, so far developed in the entire transportation field, is the electric motor, with its constant rotary effort, or torque, and with its almost infinite capacity for automatically absorbing and transforming electric power into a rotary effort. A little 25 horse-power car motor can be overloaded 100 per cent. or more if the occasion requires, and will take current until its wires actually melt in the process. There is no such reserve power in any form of reciprocating motion engine—no such constant torque, and no such ease of control. Compressed air, stored steam, gas, petroleum and other motors all have their possibilities of development, mechanically and commercially, and when proven successful in practice on any considerable scale, there will be certain portions of the general transportation field open to them, but it is equally true that the electric motor has intrinsic advantages such that it will never be displaced in street railway service, while it is certain also that it will reach into larger transportation work now performed exclusively by steam locomotives.

Before proceeding further with electric motors, a word should be said about the cable system. It would appear at first sight that here also is found a system which would fulfil the requirement of maximum acceleration and braking possibilities, and consequent high schedule speeds. Maximum acceleration can certainly be obtained with the

cable, as has frequently been demonstrated by a surly or incompetent gripman, to the great discomfort of passengers, but no cable line can compete with a parallel electric line in point of schedule speed, for the reason that the maximum speed is limited to the speed of the cable, and the latter must be kept down to a point such that slippage through the grip is not continuous. In other words, there is little possibility that cable cars, once behind their schedules, can catch up to them unless by rare good fortune in not being required to stop for passengers, while with the electric cars there is always the possibility of flying through the streets in the suburban or less congested streets, so as to make up time lost elsewhere. As a matter of fact, the cable is disappearing from American street railroads, partly because it is not popular, as it is found that the people always prefer parallel electric lines because of the greater smoothness in running, and partly because of the greater economy in operation, demonstrated again and again in our leading cities, where both motive powers have been used. The cable system is a complicated one, with its immensely costly and cumbersome street construction, which requires constant care and attention, and it is true, moreover, that a cable line cannot be sectionalized to the extent that an electric line can be done, to the end of minimizing the stoppage of traffic.

Granting, therefore, that the electric motor is the city transportation agency of the present and the future, there remains to be considered the relative advantages of the overhead system, the conduit system and the storage-battery system. In spite of numerous attempts to put the latter system upon a commercial basis, it has not yet been demonstrated to the satisfaction of street railway managers that it can be used with economy on a large scale or that good acceleration and grade-climbing work can be done where storage batteries alone are depended upon for reserve and contingency requirements. The equipment of the Chicago and Englewood Street Railway with storage batteries is about the only ambitious experiment on a scale that is now being tried in this country, but abroad batteries are used quite largely and successfully in what is called the "mixed

system," in which the overhead-trolley system is used for suburban and outlying lines, and storage batteries for the business centers. The great difficulties in the way of storage-battery work for transportation purposes lie in the great weight of the batteries to be transported, the deterioration of the plates, particularly when called upon for the widely varying power requirements of a street car, and the somewhat sluggish action of the cars in acceleration. It is by no means unreasonable to hope, however, that improvements will come in this line such that commercially successful storage-battery cars may be made possible.

The central-station method of operating street railway systems, particularly by electricity, has many intrinsic advantages. In the first place, power can be generated at such stations in large quantity and at extremely small expense. It is probable that in the largest street railway power station in the world, now building in New York, the cost of power will be reduced to $\frac{3}{4}$ of a cent per car mile, or less than 8 per cent. of the total operating expenses of the system, this cost including all losses of generation, conversion, transmission and reconversion. The inherent advantages and possibilities of electric transmission for power purposes are such that it is difficult to conceive of a more perfect adaptation of means to the desired end. When, however, the matter of transmission is taken up in detail, three methods present themselves for selection, the overhead-wire system, the open-slot conduit system, and the surface-contact, or "button system."

The overhead-wire system is the one in almost universal use, and the wisdom of its adoption has been completely justified in a large majority of cases. It is inexpensive to install, as compared with the other two systems; it is, when well put up, probably more economical than either, and troubles can be easily located and quickly remedied. Its chief disadvantages from the public point of view is the so-called unsightliness of poles and wires. In the early days of electric traction, there was certainly grave cause for complaint about this feature, but since then the improvements have been so radical that it has no longer great force, while

the danger of falling wires and of obstruction to firemen in the discharge of their duty has also been done away with to a very large extent, so that there are to-day as few accidents of any kind from the operation of trolley cars in our principal cities as could possibly be expected, in view of the immense number of passengers carried, and the congested conditions of the streets.

The surface-contact, or "button system," is not in use on any large scale in this country, but a large installation has just been made in Monaco, which is said to be working successfully. The chief trouble with this system lies in the employment of a great number of pieces of mechanism, more or less complicated, and liable to failure, the number usually being 500 at least per mile of single track. Theoretically, the system is an excellent one and has many points of advantage, but it has not come into common use as yet, and time only will tell whether or not the mechanism can be kept in good working order indefinitely without constant danger of "tie-ups" or delays.

The open-slot conduit system is in use in America only in New York City and Washington. In New York it has cost probably ten times as much as an overhead system would have cost to accomplish the same results, and its operating expenses are probably about the same as, or perhaps slightly less than those of the equivalent overhead-trolley system.

The city of Glasgow, Scotland, in common with many other British and European cities, has before it to-day the problem of determining which of these three varieties of electric traction shall be adopted. Glasgow has had some experience with the overhead system, and knows that it is reliable, reasonable in first cost, and economical in operation. The favorable results obtained on the conduit lines of New York, Washington and a few European cities have been studied in Great Britain and elsewhere with the greatest care and interest, and yet it has been determined in Glasgow and other places to use the overhead system in preference to the conduit. The fact is that it is only in cities where great traffic density obtains, and where the

mileage to be equipped is comparatively small, that it is possible to pay interest upon the enormous investment requisite for the conduit system, and this is particularly true if this investment has to be piled up upon that for previous improvements, such as the equipment of horse lines with the overhead system. Moreover, the climatic conditions must be favorable in order that success with any form of conduit system may be assured, and the sewerage system must be perfect; for, unless the conduit can be kept perfectly clean and free from snow and accumulations of water, serious electrical troubles will occur, which may tie up a railway in whole or in part. If the street railways in this country now operating on the overhead electric system were compelled to change to the conduit system over their entire lines or any large portion of them, financial ruin would undoubtedly be the consequence.

All these problems of motive power have had to be faced by managers in this country, and are now before the tramway managers of Europe. They are wise in their generation who have looked and are looking forward to the future of their properties and of the cities in which they are located, and who recognize the importance of the part which local transportation plays in the onward march of a great and constantly growing city. The real interests of the people and of the private capital engaged in street railroading are, or should be, substantially the same. The ideal system for both is one which can be handled with the greatest certainty in operation, and which can be indefinitely extended into suburban territory in advance of population without too great cost and without the necessity of transfers, and which can be built at minimum expense for the advantages given. It cannot be for the public interest to load down street railway companies with constantly increasing burdens, such as the adoption of the most costly forms of motive power, if cheaper would answer the purpose; for, by doing so, they thus postpone still further the time when any reductions can be made in fares or a system of profit-sharing with the city can be established.

[*To be Concluded.*]

NOTES AND COMMENTS.

ELECTRICAL EQUIPMENT OF A STEAM RAILWAY.

An interesting case of the successful conversion of a steam railroad into an electrically operated one is that of the Buffalo and Lockport Branch of the Erie Railroad, which runs from Tonawanda to Lockport, N. Y. The new equipment consists of two 36-ton electric locomotives for freight service, and ten electric motor cars for passenger service. The new system was put in operation last summer, and is said to be giving the greatest satisfaction. The electric cars are run at intervals of one-half hour, instead of the large intervals between trains, as was the custom with the steam road, so that five cars at this rate are required to operate the twenty-five miles of railway between Buffalo and Lockport. On their first trip the electric cars attained a speed of fifty miles an hour, including stops.

The transformation of this line from a steam to an electrically operated road, the *Iron Age* says, marks an important step in the employment of current on the steam road. If in its operation it successfully attains the results expected, it will conclusively prove that electricity can be economically applied to the operation of branches and feeders of steam trunk line systems. It would be too much to expect an immediate conversion of these latter main lines from steam operation to operation by electricity, but with electric locomotives and motor cars profitably carrying on both freight and passenger traffic on their feeders, the entering wedge will be driven still further and the ultimate result will be so much nearer of attainment. W.

FUTURE OF THE GAS ENGINE.

The *British Journal of Gas Lighting* publishes an interesting paper lately read by Mr. W. C. Peebles before the North British Association of Gas Managers. In this, the author gives a historical sketch of the development of this type of motor and discusses the lines along which the gas engine is likely to be further developed as a commercial machine in the future.

Mr. Peebles' views are summarized in the following conclusions: "There can be no doubt that a great deal has yet to be done to improve the action of the gas engine. The main direction in which a change is to be looked for is, I think, in the cycle. But this would seem to be almost impossible without introducing complicated mechanism. At present—at least with the smaller sizes—the successful competition of the gas engine with the steam engine is due chiefly to the convenience and economy with which the gas engine can be operated, especially for intermittent work. With engines above 40 or 50 horse-power, using producer gas, the cost of working as compared with steam is very greatly in favor of the gas engine, as has been proved time after time. We shall find, therefore, that the large gas engines will not stop at 400 or 500 horse-power, but will increase gradually until they compete in power with the largest steam engines made." W.

THE "SKY-SCRAPER" NOT A MODERN INSTITUTION.

Professor Lanciani, according to *Architecture and Building*, has been making some curious discoveries in reference to the building laws in force in ancient Rome, from which it would appear that the extravagantly high buildings which we are accustomed to consider as exclusively American in origin, were quite well known in Rome, and were the subject of restrictive legislation, for much the same reasons that they are objected to to-day, viz.: dangers from fire, danger from deterioration of the strength of the structures themselves, complaints of the darkened streets, etc.

The following, from the journal above named, will serve to explain the situation as disclosed by Professor Lanciani's researches:

"There are frequent allusions among the Roman historians * * * to the enormous height of the tenement buildings of Rome, but no definite figures are given until the days of Augustus, when a law was promulgated by the Senate which fixed the height of new structures at 60 feet on the street front without making any allusion to the height of the rear. It is, however, known that, in the rear, these tenement buildings rose often several stories higher than in the front, so that from a distant height, as from the top of a temple which commanded an extensive view, a row of tenement buildings in Rome presented the appearance of a terrace--highest in the rear and descending by stories toward the front. The law of Augustus applied to new buildings, respect, then as now, being shown for investments already made. The number of stories on the street front of these Roman buildings was generally ten or twelve, with fourteen or fifteen in the rear. The lowest stories were 8 or 10 feet in height, but from accounts given by writers of that time, the stories would appear to have gradually diminished as their height above the ground increased, so that the topmost tenants lived in quarters where very often they could not stand erect.

"That the stories were sometimes much less than 5 feet is shown by the discoveries in Pompeii, where, in a house inhabited, presumably by poor tenants, a story of 4 feet 3 inches has been discovered. This was a living room, too, for in it were found all the articles which pertained to Roman housekeeping--cooking utensils, beds, stools, mirrors, combs, brushes and other things, which, with the bones of the family, furnished indisputable evidence that the room had been occupied. * * * That the tenement houses of Rome towered at least 100 feet above the street in front, and 125 to 130 feet in the rear, is certain, for the promulgation of an edict limiting the height to 60 feet in front, indicates that this height had been so greatly exceeded in so many cases, that the public safety was believed to be imperilled. How many stories were contained in these tenements is conjectural, but if the upper stories were no higher than that of the house in Pompeii, the Roman tenements may have contained as many or more stories than the modern office building."

Franklin Institute.

[*Proceedings of the stated meeting held Wednesday, March 15, 1899.*]

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, March 15, 1899.

MR. JOHN BIRKINBINE, President, in the chair.

Present, 172 members and visitors.

Additions to membership since last report, 45.

The Actuary reported the gift of the sum of One Thousand Dollars from Mr. John T. Morris, for the foundation of a fund to be known as the "James T. Morris Memorial Fund," the income of which is to be devoted to the purchase of books on mechanical subjects for the library of the Institute. It was also reported that the sum above named had been received and placed in the hands of the Board of Trustees for investment.

It was voted that the action of the Board of Managers in accepting this gift be endorsed, and that the thanks of the Institute be tendered to the donor.

Mr. E. G. Acheson, of Niagara Falls, N. Y., presented a paper on "Graphite and its Artificial Manufacture," which was illustrated by the exhibition of a number of specimens, showing the partial and complete conversion of carbon into the graphitic state by the electric-furnace process devised by the speaker.

The subject was referred to the Committee on Science and the Arts for investigation and report.

Mr. Philip Mauro, of Washington, presented a communication on the "Development of the Talking Machine," particularly referring to the graphophone and its most recently improved form—the Graphophone-Grand. The paper was illustrated by the exhibition of the old and new forms of the apparatus, with which a number of demonstrations were made.

The subject was also referred for investigation.

The President called attention to the fact that a bill was now pending in the Legislature of the Commonwealth providing for an annual expenditure of $20,000, to be met by an equal sum supplied by the Federal Government, to be devoted to the making of a topographical and geological survey of the State. The President made some comments upon the importance of this contemplated work to the citizens of the Commonwealth, whereupon it was voted "that if upon investigation it should appear that the bill above referred to fully meets the requirements, the President and Secretary of the Institute be authorized to transmit the approval of the Institute of the bill now pending in the Legislature making an appropriation for the conduct of a topographical and geological survey of the State of Pennsylvania."

The President announced the following Standing Committees of the Institute for the current year:

Committee on Library.

Prof. F. L. Garrison,	Dr. Harry F. Keller,
Mr. Louis E. Levy,	Mr. Arthur Falkenau,
Prof. Geo. F. Stradling,	Mr. Benj. S. Lyman,
Dr. Isaac Norris,	Mr. A. M. Greene, Jr.,
Mr. Edwin S. Balch,	Mr. Wm. M. Barr.

Committee on Meetings.

Mr. Washington Jones,	Mr. James Christie,
Mr. Spencer Fullerton,	Mr. J. Y. McConnell,
Mr. Henry R. Heyl,	Mr. Geo. H. Taber, Jr.,
Prof. Jos. W. Richards,	Mr. W. N. Jennings,
Prof. Geo. A. Hoadley,	Dr. A. E. Kennelly.

Committee on Meteorology.

Prof. Geo. A. Hoadley,	Mr. Jos. T. Richards,
Prof. Edgar Marburg,	Mr. Henry Gawthrop,
Mr. L. Y. Schermerhorn,	Mr. Geo. S. Webster,
Mr. Henry Birkinbine,	Mr. John E. Codman,
Mr. Thomas Shaw,	Prof. L. F. Rondinella.

Committee on Cabinet of Models.

Mr. Henry Howson,	Mr. Francis Schumann,
Prof. A. J. Rowland,	Mr. Frank M. Sawyer,
Mr. Philip Pistor,	Mr. Chas. H. Gifford,
Mr. L. L. Cheney,	Mr. John G. Baker,
Mr. W. L. Boswell,	Mr. Strickland L. Kneass.

Committee on Cabinet of Minerals and Geological Specimens.

Mr. Benj. S. Lyman,	Dr. Lee K. Frankel,
Dr. Wm. C. Day,	Prof. Lyman B. Hall,
Mr. E. V. d'Invilliers,	Dr. Wm. H. Greene,
Mr. Theo. D. Rand,	Mr. Andrew A. Blair,
Mr. Clarence S. Bement,	Dr. F. A. Genth, Jr.

Committee on Cabinet of Arts and Manufactures.

Mr. Edw. T. Child,	Mr. John Haug,
Mr. Cyrus Chambers, Jr.,	Mr. Benj. H. Gledhill,
Mr. S. M. Vauclain,	Mr. James M. Dodge,
Mr. John F. Simons,	Mr. H. F. Colvin,
Mr. Henry J. Hartley,	Mr. A. E. Outerbridge, Jr.

Adjourned.

WM. H. WAHL,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

[*Abstract of proceedings of the stated meeting held March 1, 1899.*]

PROF. EDGAR MARBURG in the chair.

Reports on the following subjects were considered:

Machine and Cutter for Generating Gear-Teeth.—E. R. Fellows, Springfield, Vt.

Laid over one month.

The following were adopted:

Gas Composimeter.—Uehling and Steinbart Harrison, N. J.

ABSTRACT.—This device is designed specially for the purpose of analyzing and recording the percentage of carbonic acid in furnace and flue gases, and is continuous in operation. It is identical in principle with the Uehling and Steinbart pyrometer, lately investigated by this Committee. Both instruments employ, as a measure, the reduction in volume of the gases, which takes place in a chamber, of which two apertures form respectively the inlet and outlet, and through which the gas is constantly drawn by suction. If, from the stream of gas flowing through this chamber, one of the constituents is continuously removed by absorption (say carbonic acid by caustic alkali), a reduction of volume takes place.

Every change in the volume of the constituents absorbed from the gas causes a corresponding change of suction in the chamber, and this change is assumed to be a true measure of the percentage of the constituent in the gas to be measured.

The apparatus may be applied to a single boiler or furnace or to a number. In the latter case, a single aspirator is employed of sufficient size to produce the required suction for all, controlled by a single large suction regulator.

A simple recording apparatus is employed, by which a graphical chart showing the condition of the combustion in the furnace (or furnaces respectively) is continuously exhibited to the operative in charge. This combination adds greatly to the practical value of the device. The details of the device can only be made intelligible with the aid of illustrations.

The investigating committee made a number of tests of an apparatus of this description installed in the Spreckels' Sugar Refinery in Philadelphia, on which its report is based.

The report is favorable. The results obtained in a number of observations with the apparatus, when compared with the results of chemical examination of the flue gases withdrawn for comparison, exhibited a satisfactory uniformity.

The committee recommends the grant of the John Scott Legacy Premium and Medal to the inventors. [*Sub-Committee.*—John M. Hartman, Chairman; James Christie, Harry F. Keller.]

Universal Trimming Shear.—Reinhold Bettermann, Johnstown, Pa.

ABSTRACT.—This invention consists in concaving the cutting side of the blade of a shear, between the cutting and upper edges, so that, in cutting

curved shapes, as the sheet is fed longitudinally with the line of cutting, it can also be forced sideways into the recess in the upper blade, thus continually altering the line of cut, and producing curves of shorter radii than can be cut with shears having the upper blade a plane surface.

The report finds that concaving the blade weakens the cutting edge and would cause it to crumble in heavy work; also, grinding the cutting edge of a concave blade would cause cleavance between the cutting edges of the upper and lower blades, requiring a liner to be inserted between the blade and the jaw. The Sub-Committee's opinion is therefore unfavorable. [*Sub-Committee.*—Spencer Fullerton, Robert D. Kinney, Henry F. Colvin.]

Power-Driven Shear with Adjustable Stroke. (Same inventor.)

ABSTRACT.—This device was invented by Mr. Bettermann as an auxiliary, but not indispensable to the successful action of his concaved upper knife for shears. It consists in dispensing with a fly-wheel in an ordinary geared power-shear, and driving the countershaft by a straight belt, and reversing it by a cross-belt, running on loose pulleys, with friction-clutches on the countershaft. The clutches are connected by levers and links with the ram, so that the motion of the ram at any desired point of the down-stroke, will reverse the countershaft and withdraw the blade before finishing its maximum cut.

In the opinion of the investigating committee, this reverse motion is utterly impracticable for shears, except, perhaps, for cutting very thin iron. There being no fly-wheel, and the shafts being reversed at every stroke, there is no momentum of continuously revolving parts, and the power of the shear is reduced simply to that derived from the belt during the time of the actual cut. [*Sub-Committee.*—Spencer Fullerton, Robt. D. Kinney, Henry F. Colvin.]

Combination Pneumatic Elevator and Grinding Mill.—C. A. Gerdtzden, Winona, Minn.

ABSTRACT.—This device consists of a vertical iron mill with a grinding plate bolted on the end of a rapidly revolving shaft. This idea is not new, although the method of fastening the bed-plate is novel. The committee, however, considers this feature impracticable in a fast-running mill.

The pneumatic-elevator feature of the invention is also old, and the committee is of the opinion that the applicant will find, as others have found, that the mill itself will not make sufficient draft to elevate material any distance, no matter how many rings are added to the mill plates. Applicant is advised that there is nothing of merit in his proposed device. [*Sub-Committee.*—A. Robinson McIlvaine, Chairman, Luther L. Cheney.]

Primary Electric Clock.—Carl Joseph Moberg, Jersey City, N. J.

This instrument is an electrically actuated clock. The report criticises adversely the escapement, the defects of the impulse, the contact (time train), the contact (striking), the striking and the gear-train supporting frames.

The construction of the pendulum bob is found to be novel. The report concludes that, while the construction presents some features which differ from that of other clocks of the same order, there are no new features which can be considered as improvements on devices which have been in use heretofore. [*Sub-Committee.*—Wm. T. Lewis, H. R. Heyl, Fred. T. Haschka, L. Breitinger.]

SECTIONS.

(*Abstract of Proceedings.*)

CHEMICAL SECTION.—*Special Meeting*, Tuesday, January 3, 1899, Dr. Wahl in the chair.

Dr. W. J. Williams, Chemist to the United States Arsenal, Frankford, Philadelphia, read a paper on "Methods for the Examination of Explosives," illustrated with specimens of various forms of explosives and apparatus for testing the same. [The paper is printed in full in the *Journal*, Vol. CXLVII, 197, *et seq.*]

Stated Meeting, Tuesday, January 17th, Dr. Richards in the chair.

The following officers were elected: President, Dr. Joseph W. Richards; Vice-Presidents, Dr. Bruno Terne, Dr. W. J. Williams; Secretary, Mr. Waldemar Lee; Conservator, Dr. Wm. H. Wahl.

Mr. Allen Hazen, of New York, read a paper on "The Clarification of River Waters." [The paper is published in the *Journal*, Vol. CXLVII, 177.]

Stated Meeting, Tuesday, February 21st, Dr. Richards in the chair.

The following communications were presented:

"A Process for Testing Metals." By Mr. Joseph Richards.

"The Laboratory Production of Asphalts from Animal and Vegetable Materials." By Dr. W. C. Day, Swarthmore College, Pa. Discussed by Dr. S. F. Peckham, Dr. Samuel P. Sadtler, Dr. Harry F. Keller. Both papers were referred for publication.

A communication was presented proposing the formation of a Photographic and Microscopic Branch of the Section. Dr. Wm. H. Greene and Dr. Wm. H. Wahl were named as a special committee to confer with the petitioners, with power to make all needful arrangements to organize the new subsection.

Special Meeting, Tuesday, March 7th, Dr. Richards in the chair.

The following communications were presented: "An investigation of the Recent Explosion in the Capitol at Washington." By Prof. Chas. E. Munroe, Columbian University, Washington, D. C. "A New Liquid Acetylene Diodide." By Dr. Edward H. Keiser, Bryn Mawr College, Pa.

Stated Meeting, Tuesday, March 21st, Dr. Richards in the chair.

Dr. H. Carrington Bolton, Washington, D. C., presented a communication entitled: "The Development of Pneumatic Chemistry," illustrated profusely with lantern slides.

ELECTRICAL SECTION.—*Stated Meeting*, Tuesday, January 24, 1899. The following officers were elected: President, Prof. Geo. F. Hoadley; Vice-Presidents, G. U. G. Holman, S. B. Locke; Secretary, George T. Eyanson; Conservator, Dr. Wahl.

Professor Hoadley, President, in the chair.

Mr. W. H. Tapley, United States Government Printing Office, Washington, D. C., read a paper on "The Practical Application of the Electric Motor to

Printing Press Machinery," which was referred to the Committee on Publication.

Stated Meeting, Tuesday, February 28th, Professor Hoadley in the chair.

The following communications were presented:

"Some Laboratory Methods in Electricity" (with illustrations). Prof. W. S. Franklin, Lehigh University.

"Notes on Some Recent Developments in Electrical Engineering." Mr. Carl Hering.

"Experimental Demonstration of a New Electrolytic Interrupter for Induction Coils." Mr. Elmer G. Willyoung.

"Experimental Demonstration of an Improved Static X-Ray Machine," made by the American Roentgen Ray Company, Boston. Mr. Balderston (Williams, Brown & Earle, Philadelphia).

Stated Meeting, March 28, Professor Hoadley in the chair.

This meeting was devoted to the presentation, in abstract, of papers on electric railway subjects, by Messrs. Frank J. Sprague, Albert B. Herrick and Edward E. Higgins. The discussion was opened by Mr. Chas. Hewett, of the Union Traction Company, Philadelphia.

MINING AND METALLURGICAL SECTION.—*Stated Meeting*, Wednesday, January 11, 1899, Mr. James Christie in the chair.

The annual election of officers resulted as follows: President, James Christie; Vice-Presidents, Dr. D. K. Tuttle and Mr. Joseph Richards; Secretary, G. H. Clamer; Conservator, Dr. Wahl.

The annual report of the Section was presented by the Secretary and approved. Ordered to be transmitted to the Institute.

The following communications were presented:

"Segregation Tests on Steel Ingots." Mr. A. W. Allen, Pencoyd Iron Works.

"The Mogollon (N. M.) Mining District." Dr. H. M. Chance, Mining Engineer.

Freely discussed and referred for publication.

Messrs. B. S. Lyman, A. E. Outerbridge, Jr., and A. W. Allen were appointed as members of the Standing Committee on Papers.

Special Meeting, Wednesday, January 25th, Mr. James Christie in the chair.

The proposition was considered that the Section should interest itself in the work of the International Association for the Testing of Technical Materials.

It was thereupon decided to recommend that the Institute as a body should join the Association.

A resolution was passed favoring an appropriation by Congress in support of a Mining and Metallurgical Bureau in connection with the work of the U. S. Geological Survey, and urging the Senators of the State of Pennsylvania to support the measure.

Mr. Geo. C. Davis, of Philadelphia, presented a paper "On the Early History of Malleable Cast-Iron in the United States."

In the absence of the author, Mr. H. P. C. Nitze, of Baltimore, Dr. Jos. W.

Richards presented for him a paper "On the Iron Ores of the Ural Mountains."

Stated Meeting, Wednesday, February 8th, Mr. Christie in the chair.

The following papers were read:

"Notes on the Reduction of Iron Ores." John M. Hartman.

"Subterranean Ice Deposits in America" (illustrated). Edwin S. Balch. (Referred for publication.)

Special Meeting, Thursday, February 23d, Mr. Christie in the chair.

Prof. J. F. Kemp, of Columbia University, New York, read a paper on "Titaniferous Iron Ores."

Freely discussed and referred for publication.

Stated Meeting, Wednesday, March 9th.

Prof. Wm. H. Burr, of Columbia University, New York, read a paper on "Some Features in the Architectural Design of Buildings," which was profusely illustrated with the aid of lantern slides. The paper evoked an extended discussion. (Referred for publication.)

Special Meeting, Wednesday, March 22d, Mr. Christie in the chair.

Prof. Angelo Heilprin, Philadelphia, gave a lecture, entitled "Observations on the Physical History of the Klondike Gold Region, with Incidents of a Recent Journey Thither." The speaker illustrated his lecture with the aid of a number of lantern views.

MECHANICAL AND ENGINEERING SECTION.—*Stated Meeting*, Thursday, January 12, 1899.

The following officers were elected: President, Wilfred Lewis; Vice-Presidents, Strickland Kneass and F. M. Jaquith; Secretary, D. Eppelsheimer, Jr.; Conservator, Dr. Wahl.

Mr. Lewis in the chair.

The subject for discussion was "Personal Reminiscences of Changes in Machine Design and Shop Practice."

The discussion was opened by Dr. Sellers, and was participated in by Messrs. W. Jones, Fullerton, Spangler, Heyl, Wiegand, Outerbridge, Fitts, Chambers and many others.

Stated Meeting, Thursday, February 9th, President Lewis in the chair.

The subject for discussion was "Traveling Cranes," and was opened by Mr. Outerbridge, and largely participated in by members and others.

Special Meeting, Thursday, February 16th, Mr. Kneass in the chair.

Prof. Wm. S. Aldrich, of West Virginia University, gave an illustrated lecture, entitled "Engineering and Naval Experiences in the U. S. Repair Steamer 'Vulcan.'"

Stated Meeting, Thursday, March 9th, Vice-President Kneass in the chair.

The subject for discussion was "The Commercial Applications of Compressed Air," opened by Mr. W. L. Saunders, of New York. A large number of members participated. Mr. Saunders' communication was referred for publication.

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